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GEOLOGY AND MINERAL RESOURCES OF THE MILLERSTOWN QUADRANGLE, PERRY, JUNIATA, AND SNYDER COUNTIES, PENNSYLVANIA

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COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF ENVIRONMENTAL RESOURCES
BUREAU OF
TOPOGRAPHIC AND GEOLOGIC SURVEY
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by Rodger T. Faill and Richard B. Wells
Pennsylvania Geological Survey

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PREFACE

This report describes the rock layers of the Millerstown quadrangle, their distribution, structure, and economic mineral products.

The stratigraphy section describes in detail the various rock formations, the characteristics by which they may be recognized, the minerals and fossils contained in them, and where each is found. Conclusions are drawn about where the sediments which formed these rocks came from, how they were transported, and whether they were deposited in streams, in the sea, or along the shore of the sea.

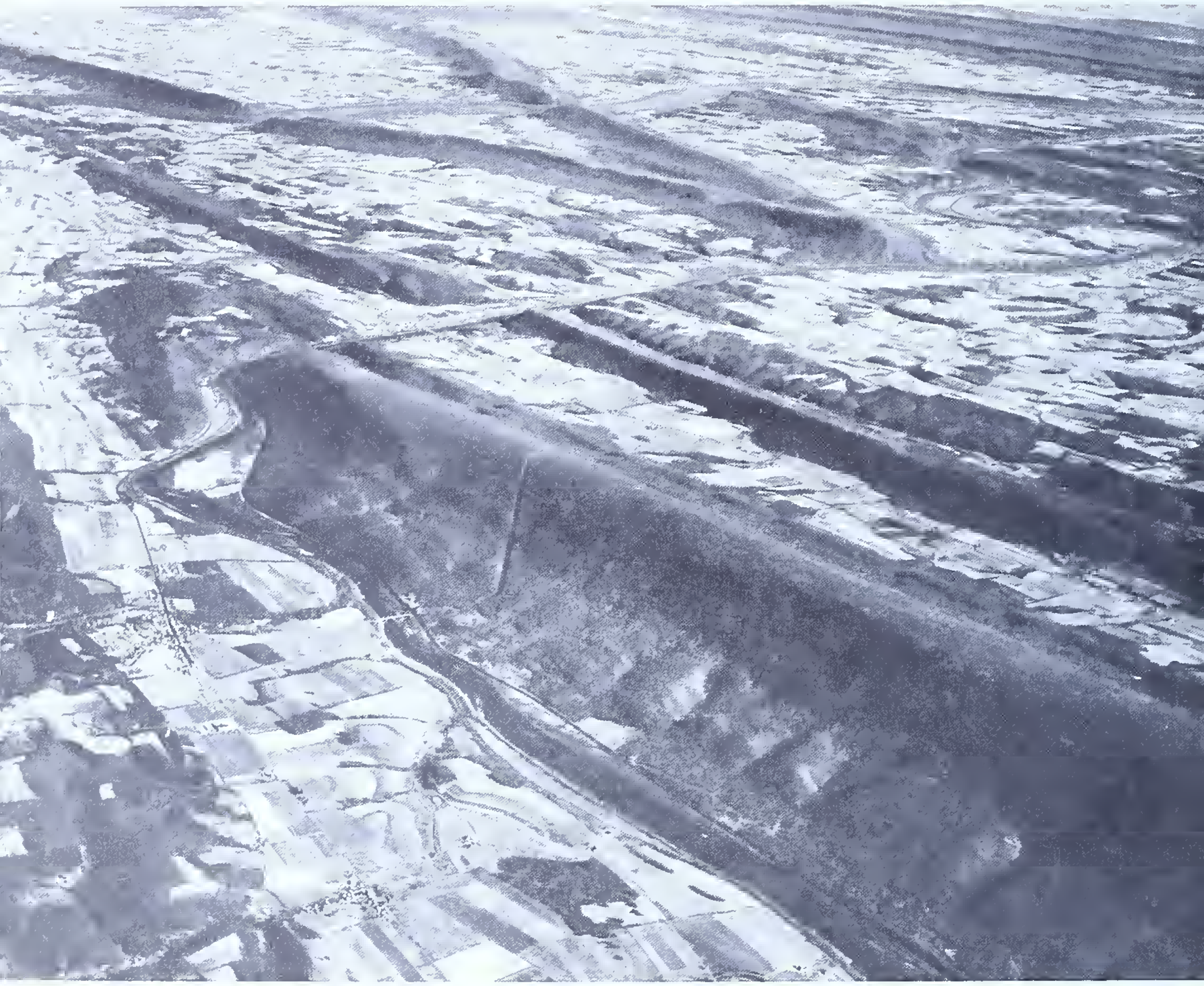
A description of the geological structure, or configuration, of the strata is presented, both as an aid in prospecting for potential economic mineral deposits, and to help in understanding the processes of mountain building and deformation which have been active here. It is hoped that this information will contribute to the understanding of the mechanism and sequence of events through which the central Appalachian Mountain chain was formed.

A chapter on economic mineral resources is included to aid in the location and extraction of mineral products. In these strata are found deposits of limestone which may be used to build roads and enrich fields, and red beds of iron ore which in former times fed the furnaces at Newport and Millerstown. Many of the low hills and valleys of the quadrangle contain beds of shale or claystone that can be used to make brick, pottery, or other ceramic products. Some of these shale beds are also quarried and used to surface the farm lanes and secondary roads which criss-cross the region. The quartzite boulders that lie on the high mountain slopes have been used in the past (and have a potential future use) in the construction of stone buildings, foundations, and railroads, and in some places are so pure that they might be a commercial source of silica.

Another section of the report deals with the geology and its influence on the human environment, through its effect on surface and underground water, foundation and excavation properties, and other engineering characteristics of the bedrock.

The text is accompanied by two colored maps and a cross section. Plate 1, a geologic map, shows the distribution of the rock formations of the quadrangle. Plate 5, an economic, engineering, and environmental map, shows the rock quarries, some of the water wells, and the orientation of fractures in the rocks. The cross section (Plate 2) shows the underground arrangement of the rock formations.

This report will be of value to land-use planners, industry, agriculture, and highway engineers.



Aerial view of southern half of Millerstown quadrangle and the surrounding area, looking southeast from the vicinity of Mexico, Pennsylvania. The Juniata River valley and Tuscarora Mountain are in the foreground, Wildcat and Raccoon Ridges cross the center of the photo, and Buffalo Mountain, Berry Mountain, Half Falls Mountain, Peters Mountain, and Blue Mountain lie beyond. The Great Valley is seen in the distance, and the rocks of the Triassic Lowlands form the horizon. The village of Thompsontown is in the foreground, and Millerstown and Newport are visible near the center of the photo. Photo by John S. Shelton, courtesy of W. H. Freeman and Company.

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GEOLOGY AND MINERAL RESOURCES OF THE MILLERSTOWN QUADRANGLE, PERRY, JUNIATA, AND SNYDER COUNTIES, PENNSYLVANIA

by

Rodger T. Faill and Richard B. Wells

ABSTRACT

The Millerstown 15-minute quadrangle is located in the middle of the Valley and Ridge province in central Pennsylvania. It is underlain by sedimentary rocks, ranging in age from Late Ordovician through Mississippian, which can be divided into two thick clastic intervals separated by a thinner nonclastic sequence. The lower clastic interval (from the Ordovician Bald Eagle Formation to the Silurian Bloomsburg Formation) consists of quartzites, sandstones and conglomerates, siltstones, shales, and minor limestones. The medial carbonate interval (from the Silurian Wills Creek Formation to the Devonian Onondaga Formation) consists mostly of limestones, with subordinate cherts, sandstones, and shales. The upper clastic interval (from the Devonian Marcellus Formation to the Mississippian Mauch Chunk Formation) consists predominantly of shales and siltstones, with some prominent sequences of sandstones, conglomerates, and quartzites.

The major structures in the quadrangle are two anticlinoria and two synclinoria having wavelengths of 8 to 11 miles. Numerous smaller folds occur within the limbs and hinges of these major, first-order folds. Kink bands, occurring in a wide range of sizes, are the underlying structural element. The deformation was basically a flexural-slip process which resulted in kink-band folds having planar limbs and narrow hinges. Faults constitute a subordinate part of the structure; most of them are reverse wedge faults representing local disruptions in the folding process. Fractures generally occur in an orthogonal system, both normal and parallel to fold axes, which suggests a genetic relation between the folds and fractures. Cleavage is only poorly developed in some of the shales and limestones, and is generally not a significant feature of the geologic structure.

One-half of the annual 40 inches of precipitation is drained by the Juniata River and the Susquehanna River just east of the quad-

rangle. Most of the remainder recharges the ground-water reservoir. Hydrologic data from 116 water wells in the quadrangle were analyzed. Water wells are generally less than 150 feet deep and usually have water-bearing zones at a depth of less than 100 feet. Yield varies with topographic location, bedrock type, and geologic formation; the optimum location for wells appears to be in valley floors underlain by limestone of the Tonoloway Formation.

The engineering characteristics of the rock units affect the location, design, construction, operation, and maintenance of engineering works. In the Millerstown quadrangle, different rock types exhibit different properties with regard to ground-water potential, foundation stability, slope stability, and ease of excavation. Each rock formation is evaluated in terms of these and other categories.

Economic mineral deposits in the quadrangle include sedimentary iron ore, agricultural lime, and building stone, which have been utilized in the past; crushed stone and clay shale, which are produced at the present time; and fluorite, wad (manganese oxide), and anthracite coal, of which only noncommercial occurrences are known.

INTRODUCTION

LOCATION AND GEOGRAPHY

The Millerstown 15-minute quadrangle lies in central Pennsylvania (Figures 1 and 2), and covers an area of 228 square miles (591 sq. km) in Perry, Juniata, and Snyder Counties. Four mountain ridges (Shade, Tuscarora, Buffalo, and Berry Mountains) cross the quadrangle in a northeast-southwest direction (see frontispiece). These are separated by lesser ridges and numerous valleys, which are connected by the narrow transverse valleys (water gaps and wind gaps) through the mountain ridges. The maximum elevation occurs on Shade Mountain (2180 feet, 664 m) and the minimum elevation is in the Juniata River as it leaves the quadrangle (473 feet, 144 m). Most of the valleys are at elevations between 500 and 800 feet (152 to 244 m). Maximum relief in the quadrangle is 1,707 feet (521 m).

One major river, the Juniata, crosses the southwestern part of the quadrangle. Approximately one-half of the drainage from the quadrangle flows into the Juniata River, whereas the other half drains eastward into the Susquehanna River.

The climate is continental, humid, and temperate with an average annual precipitation of 40 inches (100 cm), including snow accumulations averaging 61 inches (155 cm). Daily mean temperatures range from

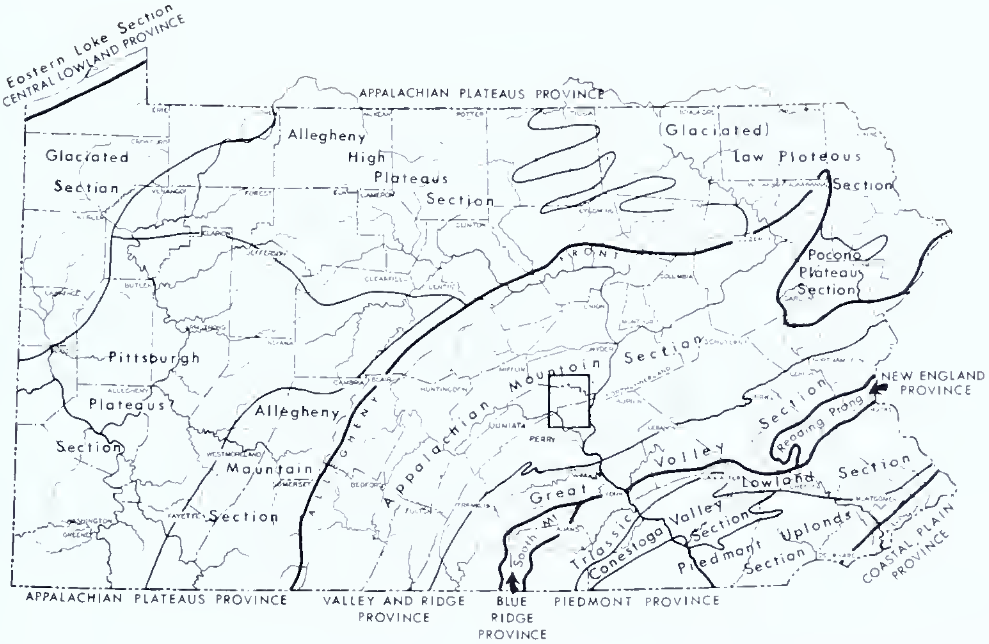

Figure 1. Location of Millerstown quadrangle with respect to the physiographic provinces of Pennsylvania.

62 to 79° F (19 to 32° C) in August, and from 25 to 40° F (−3 to 16° C) in January. Temperature extremes are −6 and 106° F (−19 and 41° C), and the mean daily temperature range in 1967 was 60.1° F (19° C) to 40.8° F (5° C). (Data from Pennsylvania Dept. of Commerce, 1969.)

Culturally, the quadrangle is largely agricultural with approximately 17 percent of the land under cultivation, 66 percent in forest land, 14 percent in grassland and 3 percent in towns and villages (Williams and Reed, 1972). The principal towns are Millerstown (1970 population, 575) in Perry County, and Beaver Springs and Mt. Pleasant Mills in Snyder County. The area is served by an excellent road and highway system, including U.S. Route 22-322 which connects Harrisburg with Altoona and Pittsburgh to the west, and U.S. Routes 11 and 15 which connect Harrisburg with Williamsport and other cities to the north. The east-west trunk line of the Penn Central Railroad follows the Juniata River. In the nineteenth century, extensive canal systems were developed on both the Juniata and Susquehanna Rivers.

The locations of towns, streams, and physiographic features mentioned in the text are shown on the toponymic map (Plate 3).

PHYSIOGRAPHY

The Millerstown quadrangle lies in the middle of the Appalachian Mountain section of the Valley and Ridge province, and the topography

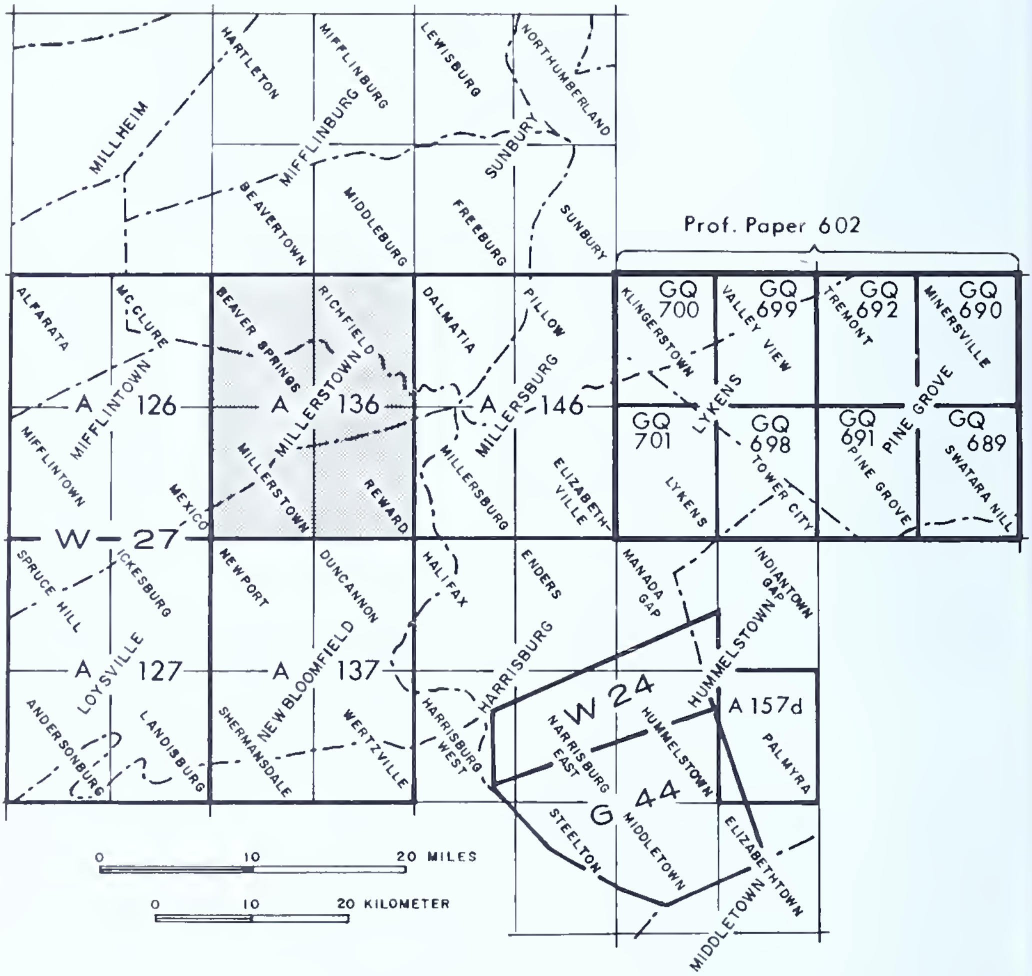

Figure 2. Topographic quadrangle designation in the Millerstown area, showing areas covered by recent geologic maps and reports.

A = Geologic Atlas report, Pa. Geol. Survey.
W = Water Resource Report, Pa. Geol. Survey.
GQ = Geologic Quadrangle Map, U.S. Geol. Survey.
G = General Geology Report, Pa. Geol. Survey.
PP = Professional Paper, U.S. Geol. Survey.

is characteristic of the entire province. Because of the wide range of rock types exposed, and the differences in weatherability and resistance to erosion among the various rock types, some stratigraphic units underlie valleys whereas others underlie higher elevations. This varied response to weathering and erosion, coupled with the generally upright folds having little or no plunge, has created a topography of long valleys and ridges.

The relative elevation at which a stratigraphic unit occurs is a gross measure of its resistance to weathering and erosion. Units which are easily weathered into small particles tend to underlie areas of low relief and low elevations. The limestones and calcareous shales, which weather readily by solution, underlie the lowest valleys because the weathering products (dissolved material and fine clays) are easily transported to stream channels. On the other hand, the quartzites and siliceous sandstones disaggregate very slowly and commonly break up along fractures and bedding planes into cobbles and boulders which are not as easily moved; these units underlie the higher ridges. Between these two extremes are, in order of increasing resistance to weathering and erosion, the claystones, shales, siltstones, and cherts. Table 1 presents the relative weathering and erosional resistance of the various rock units in the mapped area.

The Juniata River is the major stream in the quadrangle and many of the other streams drain into it (the exceptions occur in the east part of

Table 1. *Relative Resistance to Weathering and Erosion of the Various Stratigraphic Units in the Millerstown Quadrangle*

Formation Member	Relative resistance	Characteristic drainage pattern	Drainage density
Mauch Chunk	low to moderate	dendritic	medium
Pocono	very high	trellis	low
Catskill	moderate	dendritic	medium
Trimmers Rock-Harrell	low to moderate	dendritic, trellis	medium to high
Mahantango	low to high	trellis	medium
Sherman Ridge	low	trellis	medium
Montebello	high to moderate	trellis	medium
Fisher Ridge	low	trellis	medium
Dalmatia	moderate	trellis	medium
Turkey Ridge	moderate	trellis	medium
Marcellus	low	trellis	high
Onondaga	very low to low	trellis	low
Old Port	moderate	trellis	low
Keyser	low	trellis	medium
Tonoloway	very low	dendritic	low
Wills Creek	very low	dendritic	high
Bloomsburg	low	dendritic	high
Mifflintown	very low	dendritic	medium
Keefer	moderate	trellis	low
Rose Hill	moderate	trellis, dendritic	medium to high
Tuscarora	very high	trellis	low
Juniata	high to moderate	trellis	low
Bald Eagle	moderate to high	trellis	low

the quadrangle, where the streamflow is eastward into the nearby Susquehanna River).

The drainage pattern is well developed, consisting of both dendritic and trellis patterns. Drainage patterns vary with lithology to some extent, and the patterns usually associated with the various stratigraphic units are listed in Table 1. Drainage pattern is also dependent on structure; in areas of moderate to steep dip, trellis patterns predominate, whereas in areas of low dip, dendritic patterns are more common.

Drainage density is predominantly controlled by the lithology and resistance to weathering and erosion, and by the permeability of individual rock units. Stratigraphic units of low resistance, such as shales and silty shales, tend to have high drainage densities. Units of high resistance, such as sandstones and quartzites, exhibit low densities. Limestones possess low drainage densities because so much of the drainage is underground rather than surface flow. The characteristic densities for the stratigraphic units exposed in the quadrangle are listed in Table 1.

PREVIOUS WORK

The earliest geologic map covering the Millerstown quadrangle was the Geologic Map of Pennsylvania produced by the First Pennsylvania Geologic Survey (Rogers, 1858). The southern part of the quadrangle (Perry County) was remapped at a scale of 1:125,000 during the Second Pennsylvania Geologic Survey by Claypole (1885) and the northern part (Juniata and Snyder Counties) by d'Invilliers (1891). Dewees (1878) described the iron-bearing formations of the Juniata Valley, including those in the Millerstown quadrangle. No maps of this quadrangle have been published at a larger scale since that time, although Robinson (1957) mapped the geology of the southern half of the quadrangle. A number of geologic reports dealing with the rocks and mineral resources occurring in this quadrangle have been discussed by Schuchert (1943) and Merrill (1964).

A program of mapping several contiguous quadrangles in central Pennsylvania at a scale of 1:24,000 was started by the Fourth Pennsylvania Geologic Survey in the late 1950's. These quadrangles include the Loysville (Miller, 1961), Mifflintown (Conlin and Hoskins, 1962), New Bloomfield (Dyson, 1963; 1967), and Millersburg (Hoskins, in preparation) (see Figure 2 for the locations of these quadrangles). The Millerstown and Millersburg quadrangles are the last to be mapped under this program.

Work on the Millerstown quadrangle was begun in 1963 by J. P. Wilshusen, who was aided by Donald M. Hoskins and Lawrence Frakes, but was suspended after one year. Mapping was recommenced in 1965 by Rodger T. Faill, who was joined by Richard B. Wells in 1967.

ACKNOWLEDGMENTS

The authors are grateful for the advice and assistance of their colleagues at the Pennsylvania Geological Survey, particularly to Donald M. Hoskins for discussion of the stratigraphy of the quadrangle and relationships with the adjoining Mifflintown and Millersburg quadrangles, and to J. Douglas Glaeser of the City College of the City University of New York for observations and insights into the Catskill Formation. Roger G. Walker of McMaster University also provided valuable consultation on Upper Devonian stratigraphy.

Prior detailed mapping has been incorporated in this report. The mapping of the Pocono and Mauch Chunk Formations in the Buffalo-Berry synclinorium by J. P. Wilshusen and D. M. Hoskins of the Pennsylvania Geological Survey is included on the geologic map; Wilshusen's work in Slaughterback Hill, Raccoon Valley, and parts of Pfoutz Valley has been drawn on extensively; Hoskins' and Wilshusen's measured section at Wardville is included in Appendix I (locality 3).

D. M. Hoskins, Thomas M. Berg, and Stephen Herr assisted in the identification of fossils. Allen Tacker, Stephen Herr, Robert Oberman, David Rowlands, and Michael Peterson assisted in the field mapping. Drafting was done by Virginia Milewski, Albert VanOlden, and John G. Kuchinski; Terry M. Wilson and Mary Ann Miller typed the manuscript.

STRATIGRAPHY

Sedimentary rocks ranging in age from Late Ordovician through Mississippian are exposed in the Millerstown quadrangle. This sedimentary sequence is grossly divisible into two clastic intervals separated by a thinner nonclastic carbonate and shale group. The lower clastic interval includes all of the rocks from the Upper Ordovician Bald Eagle Formation through the Middle Silurian Bloomsburg Formation. This is overlain by a thinner, predominantly carbonate interval comprising the Wills Creek, Tonoloway, Keyser, Old Port, and Onondaga Formations. The strata above the Onondaga are entirely clastic, and include the interval from the Middle Devonian Marcellus Formation to the Mississippian Mauch Chunk Formation. Locally derived Pleistocene soils and gravel deposits are present in the quadrangle, along with recent unconsolidated materials.

A description of each formation is presented, with a discussion of the petrology, thickness, and outcrop characteristics. Terminology for bedding thickness used in this report was adapted, with modifications, from McKee and Weir (1953) and Ingram (1954). Beds designated very thin are less than one centimeter thick, thin beds range from 1 centimeter to two inches thick, medium beds range from two inches to two feet thick, thick beds range from two to four feet thick, and very thick beds are thicker than four feet. The crossbedding classification used is that of Middleton (1965), and color designations are taken from the *Rock Color Chart* (Goddard and others, 1948). The stratigraphic units in this quadrangle are summarized in Table 2 and their correlation with nearby areas is shown in Plate 4. For a more detailed discussion of the development of the stratigraphic nomenclature and correlations, see Schuchert (1943), Miller (1961), Conlin and Hoskins (1962), Dyson (1963, 1967), and Oliver and others (1969).

The total thickness of rock units exposed at the surface in the Millerstown quadrangle is approximately 18,250 feet (5600 m).

SYSTEMIC BOUNDARIES

The arbitrary time lines (actually surfaces) which mark the Ordovician/Silurian, Silurian/Devonian, and Devonian/Mississippian systemic boundaries have uncertain correlation through the rock units in central Pennsylvania because of the time-transgressive nature of most lithofacies and biofacies in the Appalachian basin.

In this report, the base of the Tuscarora Formation is considered to mark the beginning of the Silurian Period, more out of respect for convention than conviction. The location of this boundary has never been fully resolved, due to the lack of fossils in both the Tuscarora and the underlying Juniata Formation. The Juniata-Tuscarora contact has traditionally been mapped as the systemic boundary in central Pennsylvania because it is a distinctive, mappable contact and is approximately, if not precisely, correlative with the true systemic boundary. This contact is conformable on both Tuscarora Mountain and Shade Mountain.

The precise location of the Silurian/Devonian contact in the Tonoloway-Keyser-Old Port (Helderberg) sequence has been the subject of an unresolved controversy for some time (e.g., Ulrich, 1911; Swartz, 1939; Swartz and Swartz, 1941; Boucot, 1957; Berdan and others, 1969). Most recent work (Bowen, 1967) indicates that the Keyser Formation includes rocks of both Silurian and Devonian age. The boundary is conformable and gradational in the Millerstown area.

The Devonian/Mississippian boundary is somewhat better documented, and occurs in the Spechty Kopf Member of the Pocono Formation (Oliver and others, 1969). This boundary is located largely on the basis of plant fossils studied by Read (1955) and Wood and others (1969).

Apparently sedimentation was continuous in the area across all three of these systemic boundaries.

Table 2. *Sequence, Thickness, and General Description of the Geologic Column in the Millerstown Quadrangle*

System	Series	Rock unit	Thickness	General description
Mississippian (partial) 3,400′ (1,036 m)	Middle (Chester)	Mauch Chunk Formation Mmc	2,000′+ (610 m)	Grayish-red and gray argillaceous siltstone and silty shale; gray, medium- and coarse-grained, crossbedded conglomeratic sandstone and light-gray quartz-pebble conglomerate in lower part.
	Lower (Meramec, Osage, Kinderhook)	Pocono Formation 1,600′ (490 m) Mount Carbon Member Mpm	940′ (286 m)	Gray to buff, medium-grained, medium- to very thick bedded, crossbedded sandstone with beds and lenses of white quartz-pebble conglomerate in lower part.
		Beckville Member Mpb	225′ (69 m)	Gray to buff, medium-grained, medium- to very thick bedded, crossbedded sandstone with beds and lenses of white quartz-pebble conglomerate in lower part and rare thin coal seams.
		Spechty Kopf Member DMps	435′ (133 m)	Gray, fine- and medium-grained sandstone and dark-gray argillaceous siltstone; prominent conglomerate beds near the middle and at the base.
Devonian 11,525–12,800′ (3,513–3,900 m)	Upper	Catskill Formation 6,550–8,600′ (1,996–2,621 m) Duncannon Member Dcd	1,900–3,000′ (579–914 m)	Asymmetric, upward-fining cycles in which a basal nonred fine- to medium-grained, locally conglomeratic sandstone is overlain by very fine grained, grayish-red sandstone, grayish-red siltstone and red silty claystone. Cycles have concave erosional bases.
		Sherman Creek Member Dcs	1,500–2,700′ (457–821 m)	Dominantly grayish-red silty claystone, siltstone, and very fine grained, crossbedded sandstone, with prominent medium-gray, very fine to medium-grained, medium-bedded sandstone interval near the middle.
		Irish Valley Member Dci	2,500–3,150′ (762–960 m)	Interbedded grayish-red and light-olive-gray sandstone, siltstone, and shale, overlain by upward-fining cyclic deposits of gray sandstone, grayish-red siltstone, and silty claystone.

Table 2. *(Continued)*

System	Series	Rock unit	Thickness	General description
Devonian	Upper	Trimmers Rock-Harrell Formations Dth	Trimmers Rock: 2,000–2,500′* (610–762 m) Harrell: 200′ (61 m)	Trimmers Rock: Light-olive-gray and medium-gray siltstone and silty shale, with interbedded very fine grained sandstone in upper part. Graded bedding common in siltstone and sandstone beds. Harrell: Dark- to light-olive-gray and medium-light-gray silty shale, noncalcareous, nonfossiliferous, splintery fracture.
	Middle	Mahantango Formation 1,300–1,600′ (396–487 m) Sherman Ridge Member Dms	500–700′ (152–213 m)	Light-olive-gray, fossiliferous, silty claystone with two interbedded siltstone/very fine sandstone units which have gradational bases, sharp tops, and coarsen upward.
		Montebello Member Dmm	200–900′ (61–274 m)	Light-olive-gray, medium-light-gray to dusky-yellow, very fine to medium-grained, locally conglomeratic, siliceous, fossiliferous sandstone, interbedded with gray siliceous siltstone and silty claystone in upward-coarsening cycles.
		Fisher Ridge Member Dmf	100–700′ (30–213 m)	Interbedded olive-gray and medium-gray shale, siltstone, and very fine grained sandstone. Unit is predominantly laminated silty shale.
		Dalmatia Member Dmd	0–200′ (60 m)	Light-olive-gray, very fine to coarse-grained sandstone.
		Turkey Ridge Member Dmt	100′ (30 m)*	Light-gray to olive-gray, very fine to medium-grained, medium- and thick-bedded, planar-bedded, subgraywacke sandstone, which typically develops a spheroidal or ellipsoidal exfoliation.
		Marcellus Formation Dmr	106′ (32 m)*	Highly fissile, dark-gray to black, carbonaceous, noncalcareous shale, commonly has dark-yellowish-orange limonite staining on fracture surfaces.

	Lower	Onondaga Formation Don	165′ (50 m)	Lower part is medium-gray, highly fissile shale (Needmore Member), calcareous toward the top, overlain by medium- to dark-gray, dense, fossiliferous, argillaceous, locally carbonaceous, microcrystalline limestone (Selinsgrove Member).
		Old Port Formation Do	50–100′ (15–30 m)	Dark-gray, whitish-weathering chert, underlain by calcareous shale and thin gray limestone beds, and locally overlain by gray to buff, medium- to coarse-grained fossiliferous sandstone (Ridgeley Member).
Silurian 3,400–3,750′ (1,036–1,128 m)	Upper (Cayugan)	Keyser Formation SDk	150–200′ (46–61 m)	Medium-gray, fossiliferous, lumpy or "pseudo-nodular" limestone.
		Tonoloway Formation Sto	500–600′ (152–183 m)	Medium-gray, laminated to thin-bedded limestone with some thin beds of medium-gray calcareous shale.
		Wills Creek Formation Sw, Swu, Swl	600–800′ (183–244 m)	Predominantly gray or variegated calcareous shale with interbedded light-gray calcareous fine-grained sandstone, medium-gray limestone, and grayish-red silty claystone.
	Middle (Niagaran)	Bloomsburg Formation Sb	450–480′* (137–146 m)	Grayish-red claystone and shale; locally fossiliferous; grayish-red very fine to fine-grained, silty, argillaceous, hematitic sandstones at base and near top; contains a few thin, light-gray, fine- to medium-grained sandstones in upper part.
		Mifflintown Formation Sm	159′ (48 m)*	Dark-gray, silty, calcareous shale; medium- to dark-gray, bioclastic and micritic to microcrystalline, medium- to thin-bedded, planar-bedded limestone.
		Keefer Formation Ske	38′ (12 m)*	Light- to dark-gray, very fine to coarse-grained, fossiliferous, siliceous, very thin to thick-bedded, cross-bedded sandstone which is locally hematitic, locally conglomeratic.

Table 2. *(Continued)*

System	Series	Rock unit	Thickness	General description
Silurian	Middle (Niagaran)	Rose Hill Formation Sru, Src, Srm, Srch, Srl	950′ (290 m)*	Light-gray and light-olive-gray, slightly silty shale, calcareous in upper part; contains two units of grayish-red to reddish-black, very fine to coarse-grained, siliceous, thin- to medium-bedded, hematitic sandstone and siltstone (Cabin Hill and Center Members).
	Lower (Albion)	Tuscarora Formation St	600′ (183 m)	Light-gray to white, fine- to medium-grained, medium-bedded orthoquartzite, interbedded in upper portions with medium-gray and olive-gray silty shale.
Ordovician (partial) 1480′ (451 m)	Upper	Juniata Formation Oju, Ojl	1,100′ (335 m)	Upper part is grayish-red, very fine to medium-grained, crossbedded, graywacke sandstone; lower part is grayish-red siltstone and silty claystone.
		Bald Eagle Formation Obe	730′ (223 m)	Gray, medium- to thick-bedded, crossbedded, medium- to coarse-grained sandstone and quartz-pebble conglomerate.

Summary:	Mississippian (partial)	3,400 feet (1,036 m)
	Devonian	11,525 to 12,800 feet (3,513 to 3,900 m)
	Silurian	3,400 to 3,700 feet (1,036 to 1,128 m)
	Ordovician (partial)	1,480 feet (451 m)
	Total	19,805 to 21,430 feet (6,037 to 6,532 m)

* Designates unit with measured section in the quadrangle.

Most of the rock formations present in the quadrangle represent sediments deposited in environments which migrated laterally through time. Thus, the formation contacts shown on the geologic map and cross sections do not delineate time-rock units. The one notable exception to this is the Tioga bentonite, which essentially marks a time plane in the Middle Devonian Series.

ORDOVICIAN SYSTEM

Recent papers describing the older Ordovician strata in central Pennsylvania that are present in the subsurface of the Millerstown quadrangle are: McBride (1962), McIver (1970), and Carswell and others (1968) on the Martinsburg Formation; Horowitz (1965) and Thompson (1970a) on the Reedsville and Bald Eagle Formations; MacLachlan (1967) on the carbonate rocks; and Bretsky (1969) on the Martinsburg and Reedsville Formations.

Bald Eagle Formation

Name and Extent

The Bald Eagle Formation is the oldest rock unit present at the surface in the quadrangle. The formation was named by Grabau (1909) after Bald Eagle Mountain near Tyrone in Blair County, Pennsylvania. Rogers (1858) had previously termed the Bald Eagle Formation the Levant Gray Sandstone. Exposures of the Bald Eagle are restricted to the Valley and Ridge province in central and southern Pennsylvania. A medial conglomeratic interval, named the Lost Run Conglomerate Member by Swartz (1955), is present from Tyrone to the Lost Creek area on Shade Mountain.

The Bald Eagle has been considered by some (Willard and Cleaves, 1939; Miller, 1961; Dyson, 1967) to be a member of the Juniata Formation. Although its contact with the Juniata is gradational and variable (Thompson, 1970a), it is felt that it is sufficiently distinctive from the Juniata to be considered a separate formation.

Character

The only outcrop of Bald Eagle found in the quadrangle exposes sandstone and conglomerate, pinkish-gray, gray, and light-gray-brown, very thick bedded (6 to 10 feet or 1.8 to 3 m), and crossbedded, with pebbles of quartz, quartzite, sandstone, and chert in a matrix of medium- and coarse-grained, poorly sorted graywacke sandstone. The pebbles are well rounded to subangular, and generally in the ¼ to 2 inch (0.6 to 5 cm) size range. The maximum observed pebble diameter is three inches (7.6 cm). A reference section for the Lost Run Member, along Pa. Route 235, approximately one mile (1.6 km) west of the west edge of the Millerstown quadrangle, was measured by Conlin and Hoskins (1962).

Krynine and Tuttle (1941) described the lithology of the Bald Eagle as a typical gray, greenish, or black graywacke, which in places is conglomeratic. They reported a consistent petrographic composition of about 50 percent angular quartz grains, 10 percent clay, 3 to 5 percent feldspar, 40 percent or more rock fragments (including slate, phyllite, argillite, and schist), and heavy minerals such as tourmaline, zircon, iron minerals, hornblende, and kyanite. Thompson (1970b) investigated the red color in the upper Ordovician clastic sediments across central Pennsylvania, and concluded from the nature of the chlorite, iron-oxide content, clay minerals, and the nature of the red-nonred color boundary that the Bald Eagle and Juniata Formations are both part of the same sandstone unit. According to Thompson (1970b, p. 599), ". . . the red pigment was diagenetically removed from the lower (Bald Eagle) portions of an initially all-red sequence by aqueous reduction and dissolution, with generation of iron-rich clay-mineral phases stable in a saturated environment."

Horowitz (1969, 1971) independently arrived at the same conclusion, i.e., that the red-nonred color boundary in the Juniata and Bald Eagle (or Oswego) is of diagenetic origin. Horowitz (1971) cited evidence that the color change from red to drab involved the chemical reduction of iron by the upward movement of solutions which originated in the underlying Reedsville shale. The migration paths of these reducing solutions were influenced by permeability variations within the rock, and by the influx of meteoric water from the east and the development of a hydraulic gradient to the west.

Outcrop Area and Thickness

The Bald Eagle Formation is approximately 730 feet (223 m) thick in the reference section on Shade Mountain described by Conlin and Hoskins (1962). This formation is more resistant to erosion than the underlying Reedsville Formation, and forms a prominent secondary ridge in the center of Shade Mountain for about ten miles (16 km) westward from Lost Creek in the Mifflintown quadrangle.

Formation Boundaries

Both the upper and lower contacts of the Bald Eagle are concealed in the Millerstown quadrangle. Where Kishacoquillas Creek crosses Jacks Mountain some 17 miles (27 km) west of the quadrangle, the contact with the underlying Reedsville Formation is conformable and gradational. The contact with the overlying Juniata Formation is gradational in the Mifflintown quadrangle (Conlin and Hoskins, 1962).

Age

The exact age of the Bald Eagle is unknown because of the absence of fossils. An age assignment of Upper Ordovician (Cincinnatian) has been accepted on the basis of stratigraphic position (Twenhofel and others, 1954). Willard (1943) states that the Bald Eagle and Juniata Formations are of Maysville-Richmond age (medial Cincinnatian stages).

Sedimentation

The petrographic composition, crossbedding, channel scours, grain size, and bed thickness indicate a nonmarine, fluvial environment of deposition for the Bald Eagle Formation. The conglomeratic sandstone of the Lost Run Member is apparently a braided-stream or alluvial-fan deposit.

Yeakel (1959, 1962) found a consistent northwestward flow direction indicated by the sedimentary structures, principally crossbedding, in the Bald Eagle and Juniata Formations. The mean dip azimuth for more than 1700 crossbedding measurements at 60 localities in the central Appalachians was 300°. This paleoslope direction was verified by a systematic northwestward decrease in the average maximum pebble diameter in the conglomerates. Yeakel interpreted the Bald Eagle environment as a fluvial coastal plain bordered by alluvial fans.

Thompson (1967) reported that a change from marine to nonmarine sedimentation occurs within the Bald Eagle Formation. This marine regression has been linked to the Taconic orogeny (Willard, 1943 and Horowitz, 1966) which elevated highland source areas to the east and southeast, and produced a broad, westward-thinning wedge of detritus which now forms the Bald Eagle, Juniata, and Tuscarora Formations. These are the units which are collectively referred to as the Mid-Paleozoic molasse of the Taconic clastic wedge (Potter and Pettijohn, 1963).

Horowitz (1966) related the deposition of the Bald Eagle to the underlying formations, and concluded that the marine regression in the upper Ordovician involved the prograding of a band of coalescing small deltas which developed during the Taconic uplift. The Bald Eagle may represent part of the subaerial topset beds of these coalescing deltas.

Juniata Formation

Name and Extent

The name Juniata Formation was proposed by Darton and Taff (1896) for rocks formerly referred to as Red Medina Sandstone in New York State or the Levant Red Sandstone in Pennsylvania (Rogers, 1858). The Juniata Formation and its northern equivalent, the Queenston Shale, form a broad lens of red sediments that stretches from western New York into Tennessee and northern Alabama.

Character

The Juniata Formation consists of sandstone, siltstone, and silty claystone in various shades of grayish red. The sandstones are very fine to medium- (and locally coarse) grained, poorly sorted, angular to subangular graywacke and subgraywacke. The sand typically includes about 20 percent fine-grained rock fragments, up to 15 percent opaque mineral grains, and 20 percent silt and clay matrix, and contains thin zones of grayish-red shale pebbles. The unit is generally medium bedded; trough-type crossbedding is common (Figure 3).

Outcrop Area and Thickness

The Juniata Formation is exposed on Shade Mountain anticline, underlying the crest of the mountain from the west edge of the quadrangle to the Beavertown Fire Tower. A good exposure of part of the Juniata can be seen on the east side of Pa. Route 235 where the road crosses Shade Mountain five miles (8 km) south of Beaver Springs. As calculated from the geologic map, the Juniata is approximately 1,100 feet (335 m) thick in the Millerstown quadrangle. Thickness measurements of the Juniata Formation at nearby localities are presented in Table 3.

Formation Boundaries

Both the upper and lower contacts of the Juniata are conformable in this area. The basal contact with the Bald Eagle Formation was discussed in the previous section. The Juniata-Tuscarora contact at Romig Gap is a transition zone approximately 60 feet thick consisting of interbedded grayish-red argillaceous sandstone of Juniata affinity, orthoquartzite typical of the overlying Tuscarora Formation, and a transitional lithology. These transitional beds are pink, very fine to medium-grained orthoquartzites which are informally called the "pink Tuscarora."

The Juniata-Tuscarora contact zone is also well exposed at Run Gap on Tuscarora Mountain (Mifflintown quadrangle).

Age

The Juniata Formation has traditionally been considered to be Upper Ordovician (Richmond Stage, Cincinnatian Series). This age assignment is not definitive because recognizable fossils have not been found in it, nor in the underlying Bald Eagle Formation (Yeakel, 1962). The Reedsville Formation which underlies the Bald Eagle and Juniata in this area contains a distinctive fauna of late Trenton (Champlainian) to Maysville (Cincinnatian) age (Willard, 1943). The overlying Tuscarora Formation has been dated at Lower Silurian (Albion) age on the basis of microfossils (Cramer, 1969). Thus the age of the Juniata is bracketed but not defined.

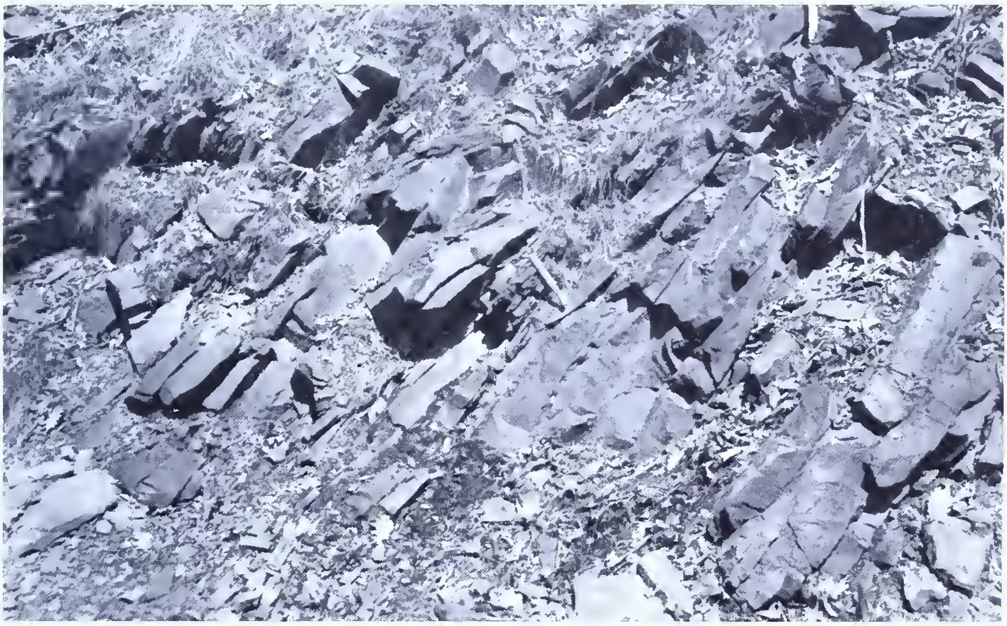

Figure 3. Ordovician Juniata Formation exposed on east side of Pa. Route 235 at Romig Gap on Shade Mountain.

Sedimentation

The lithologic character, sedimentary structures, and absence of fossils in the Juniata indicate that this formation is a nonmarine, fluvial or delta-plain deposit. This interpretation is supported by the work of Willard (1943), Folk (1960), and others. Yeakel (1959) measured a mean dip azimuth of 300° on 2,254 sets of festoon crossbeds in the Juniata in Pennsylvania and Maryland. The Juniata sediments were deposited by streams which flowed generally northwestward from a source area which was uplifted during the Taconic orogeny (Stose, 1930). The broad zone of deposition, which separated a rising source area to the east from a shallow, epeiric sea in the continental interior to the west has been called the Queenston Delta (LaPorte, 1968).

Thompson (1970a) concluded that both the Juniata and most of the underlying Bald Eagle Formation had a similar primary origin in a nonmarine, fluvial environment of deposition. According to Rogers (1958), the Juniata and its correlative, the Sequatchie Formation, comprise a clastic wedge which is present from Alabama to Quebec and reflects the main pulse of the Taconian orogeny.

SILURIAN SYSTEM

The rocks of the Silurian System show a general decrease in grain size from medium-grained sandstone in the lower part to clay shales and

Table 3. *Thickness Values for the Ordovician Juniata Formation in Central Pennsylvania*

Locality	Quadrangle*	County	Thickness (feet)	(meters)	Source
Long Mountain, Milroy, Pa.	Lewistown	Mifflin	550	168	Swartz, 1934
Tuscarora Mountain, McConnellsburg, Pa.	McConnellsburg 7½′	Fulton	53	16	Pierce, 1966
East Blue Mountain Tunnel, Pa. Turnpike	Shippensburg	Franklin	729	222	Willard and Cleaves, 1939
Loysburg Gap	Everett	Bedford	1,028	313	Knowles, 1966
Kishacoquillas Gap, Reedsville, Pa.	Lewistown	Mifflin	1,660	506	Clark and Stearn, 1960
Susquehanna Gap, Marysville, Pa.	Harrisburg	Cumberland	84	26	Dyson, 1967
McAllister Gap, Shade Mountain	Mifflintown	Juniata	1,130	344	Conlin and Hoskins, 1962 (calculated from geol. map)
Spiglemeier Gap, Shade Mountain	Mifflintown	Juniata	975	297	Conlin and Hoskins, 1962 (calculated from geol. map)
Lost Creek Gap, Shade Mountain	Mifflintown	Juniata	1,300	396	Conlin and Hoskins, 1962 (calculated from geol. map)
Run Gap, Tuscarora Mountain	Loysville	Juniata, Perry	1,000–1,200	305–366	Miller, 1961
Doubling Gap, Blue Mountain	Loysville	Cumberland, Perry	1,000	305	Miller, 1961
Shade Mountain	Millerstown	Snyder	~1,100	~335	Faill and Wells (this report)

* Refers to 15-minute quadrangle unless otherwise stated.

carbonates in the upper part. A concomitant shift in depositional environments from fluvial to shallow marine, and in the tectonic setting of the region from a molasse basin to a stable shelf environment, is recorded in these sediments.

Age assignments of Silurian formations are given in terms of the traditional Albion, Niagaran, and Cayugan Series as defined by Swartz and others (1942) and correlated with the Standard Series of Berry and Boucot (1970) (Table 4). The Silurian series were redefined and correlated with the type European series by Fisher (1960), who recommended that the New York Silurian be used as the standard reference section for the United States, as it had been since the earliest subdivision of the New York Silurian succession by Clarke and Schuchert (1899) and Chamberlin and Salisbury (1905). Berry and Boucot (1970) suggest that, since the Silurian faunas are relatively cosmopolitan (at least throughout the northern hemisphere), and the bulk of the revised series and stages of Fisher (1960) are relatively unfossiliferous (except for the middle part) and of local use only, the European Standard Series should be utilized for correlation in North America.

The sequence of Silurian formations and their correlations are shown on the Correlation Chart (Plate 4), and the age relationships of the Silurian units are shown in Table 4. The assignment of Silurian formations as "Lower," "Middle," or "Upper" Silurian is an arbitrary device which has not been used consistently in different quadrangles in the area (see footnote 4 on Plate 4 for the exact usage on different maps). For the sake of convenience, in the Millerstown quadrangle, the Tuscarora Formation is considered to be the Lower Silurian, the Rose Hill, Keefer, Mifflintown, and Bloomsburg Formations are the Middle Silurian, and the Wills Creek, Tonoloway, and part of the Keyser Formation are the Upper Silurian. For more precise age assignments, each unit is referred to a Silurian series in the text.

The Tuscarora, Rose Hill, and Keefer Formations are clastic units composed largely of interbedded sandstone and shale. The Mifflintown, Bloomsburg, and Wills Creek are primarily interbedded limestone, shale, and silty claystone, and the Tonoloway and Keyser are limestone formations.

The Silurian System is approximately 3400 to 3700 feet (1036 to 1128 m) thick in the Millerstown quadrangle.

Tuscarora Formation

Name and Extent

The name Tuscarora was first applied by Darton and Taff (1896) to 480 feet (146 m) of white or gray, massive quartzite which overlies the

Table 4. *Subdivisions of the Silurian System*

Column 1 shows the traditional age assignments of Swartz and others (1942); column 2 correlates the American Standard Series with the type European Series. Column 3 represents current usage, as defined by Berry and Boucot (1970).

Swartz and others, 1942

SERIES	FORMATIONS
Cayugan	Keyser
	Tonoloway
	Wills Creek Bloomsburg
Niagaran	Mc Kenzie
	▨
	Rochester
	Keefer
	Rose Hill
Albion	Tuscarora

Fisher, 1960

TYPE EUROPEAN	AMERICAN STANDARD SYSTEM	AMERICAN STANDARD SERIES
Ludlow	Upper	Cayugan
	Middle	Niagara
Wenlock		
Llandovery		
	Lower	
	▨	

Berry and Boucot, 1970

STANDARD SERIES	FORMATIONS
Pridoli	Keyser
	Tonoloway
	Wills Creek
Ludlow	Bloomsburg
Wenlock	Mifflintown
Llandovery	Rose Hill
	Tuscarora

Juniata Formation in the central Appalachian Mountains. No type locality was proposed, but apparently the name was derived from Tuscarora Mountain (Plate 3). This formation has previously been referred to as the White Medina or the Levant White Sandstone (Rogers, 1858). The Tuscarora is currently recognized from Pennsylvania to Virginia and West Virginia.

Character

The Tuscarora Formation consists of an interbedded sequence of orthoquartzite and shale (Figure 4). The orthoquartzite is very fine to medium grained, medium to light gray and light olive gray, and tightly cemented with silica. (The color of the quartzite tends to fade on weathered surfaces, which commonly appear whitish; this has led to the common description of the Tuscarora as a "white quartzite.") The shale is medium gray and medium olive gray, silty to very finely sandy, noncalcareous, thin to very thin bedded and poorly fissile. The quartzite beds contain occasional angular to discoidal shale pebbles, ¼ to 2 inches (0.6 to 5 cm) in diameter, which are lithologically similar to the underlying shale beds. Both the orthoquartzites and shales are locally limonitic, having a rust-colored stain on weathered surfaces. A detailed description of the upper half of the Tuscarora Formation at Millerstown is given in Appendix I, and chemical analyses of this unit are presented in Appendix II. The lithologic composition of the Tuscarora Formation in the Millerstown section is given in Table 5.

Petrographically, the Tuscarora quartzites are composed of 95 to 99+ percent detrital quartz grains and silica cement. Grain shape, which is usually not visible in a hand sample due to the cementation, ranges from angular to well rounded, with a fair correlation of degree of roundness with increasing grain size. Grain contacts are generally sutured and embayed, and the extinction is slightly to highly undulose. Other constituents present are detrital rock fragments, illite, sericite, clay, and various accessory minerals.

The thickness of individual quartzite beds is highly variable, but is ordinarily between two inches and two feet (0.05 to 0.6 m) with a maximum thickness of 3 feet (1.0 m). Quartzite beds in the Tuscarora are subject to abrupt lateral changes in thickness (Figure 5), and crossbedding is common. Crossbedding is mainly trough type, with planar-type crossbedding and parallel lamination locally prominent. No systematic study of the vectorial properties of sedimentary structures was done for this report, but a strikingly persistent northwest dip direction was noted in the crossbeds.

The distinctive "pink Tuscarora," which occurs in the lower 50 feet (15 m) of the formation, consists of pale-red to grayish-red-purple ortho-

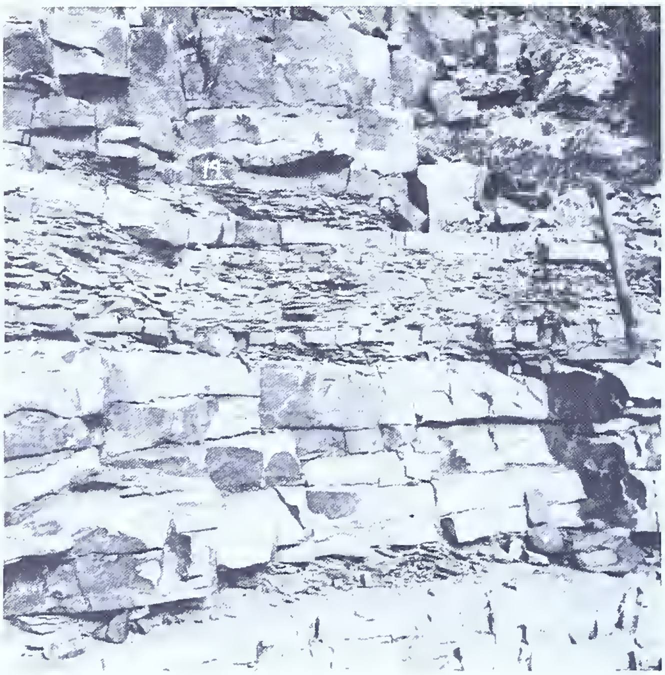

Figure 4. Detail of typical Tuscarora Formation, quartzite and shale beds. Units 17, 18, and 19, Millerstown Silurian section (Appendix I, locality 1).

quartzite and subgraywacke, which is very fine to coarse grained, siliceous, slightly hematitic, and locally contains shale pebbles. Sorting is highly variable, ranging from poor to excellent. Compared to the typical Juniata lithology, the "pink Tuscarora" has better sorting, more siliceous cement, and a lighter color. Quartz grains in the "pink Tuscarora" tend to be stained with hematite, so that in hand samples they appear to be rose quartz rather than clear quartz.

The Tuscarora Formation is essentially nonfossiliferous, except for the trace fossil *Arthrophycus alleghenensis*. These ichnofossils occur as bundles or radial groupings of arcuate cylindrical burrows which have regularly spaced transverse ridges (Figure 6a). They occur on the basal surfaces of quartzite beds, with the longitudinal axes of the tubes lying in a plane parallel to the sandstone-shale interface. The significance of these fossils as indicators of depositional environments or geologic age has yet to be established. Commonly the *Arthrophycus* tubes will branch irregularly or cross each other without intersecting, as though they were superimposed, discrete cylindrical objects rather than burrows (Figure 6b). The latter variety was called *Fucoides Allaghenensis* [sic] by Taylor (1834), who considered them to be petrified marine plants. More re-

Table 5. *Lithologic Composition, Millerstown Silurian Section*

(See Appendix 1 for description of units.)

	Shale and claystone (%)	Sandstone and quartzite (%)	Siltstone (%)	Iron sandstone (%)	Limestone (%)	Cover (%)	Thickness	
							(feet)	(meters)
Bloomsburg Formation (partial)	91	9	trace	—	—	—	23	7
Mifflintown Formation	59	—	4	—	37	—	159	48
Keefer Formation	21	77	2	—	—	—	38	12
Rose Hill Formation (total)	42	2	6	6	4	40	947	289
Upper shaly member	55	½	8½	1	35	—	116	35
Center Member	39	—	3	58	—	—	79	24
Middle shaly member	52	—	8	½	—	39½	360	110
Cabin Hill Member	—	—	—	100	—	—	12½	4
Lower shaly member	40	5	12	1	—	42	379	116
Tuscarora Formation (partial)	21	75	trace	—	—	4	270½	82

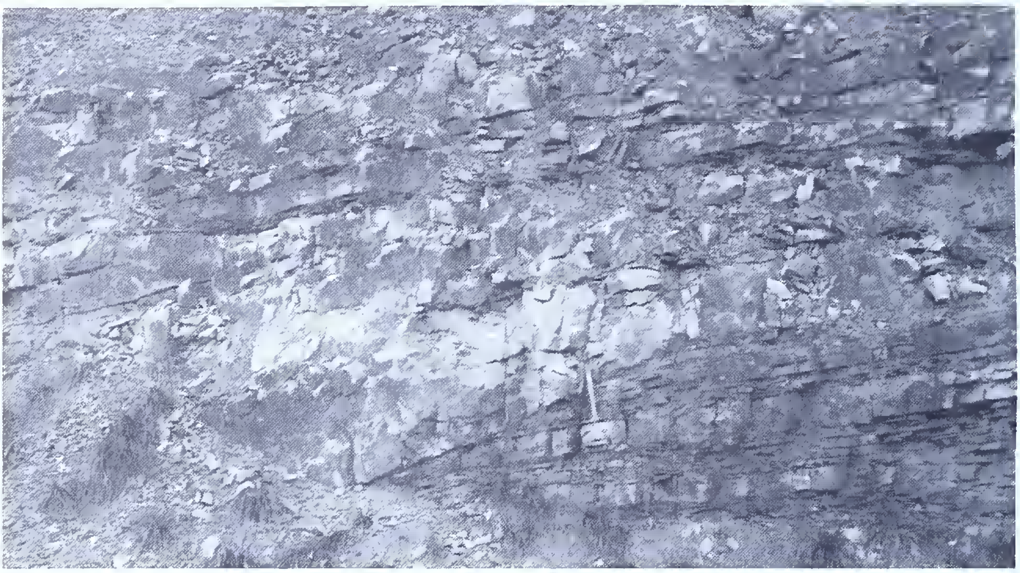

Figure 5. Tuscarora Formation exposed on the east side of U.S. Route 22-322 north of Millerstown, Perry County. Prominent quartzite bed in foreground occupies a channel scour which cuts out several feet of the underlying beds. View looking east; channel is in unit 11, Millerstown Silurian section (Appendix I, locality 1).

cently, Hantzschel (1962) and Seilacher (1955) suggested that they are feeding tubes constructed by burrowing organisms.

Cramer (1969) investigated the palynology of the Rose Hill and Tuscarora Formations at Millerstown, and reported finding Acritarch and Chitinozoan palynomorphs in the shale beds. Acritarchs are acid-insoluble organic microfossils of unknown affinity, which are thought to have had a planktonic (free-floating, aquatic) habit because of their similarity to modern planktonic dinoflagellates. The chitinozoans are cylindrical or bell-shaped chitinous foraminifera (Collinson and Schwalb, 1955).

Outcrop Area and Thickness

The Tuscarora Formation is one of the more resistant units in the Valley and Ridge province and underlies the two most prominent ridges in the quadrangle, Shade Mountain and Tuscarora Mountain. These mountains are both doubly plunging anticlines. On Tuscarora Mountain it underlies both the crest and flanks, whereas on Shade Mountain it underlies the flanks, having been eroded from the crest for most of its length. Tuscarora exposures are generally poor on these ridges, because the weathered float forms a thick scree deposit on the forested slopes.

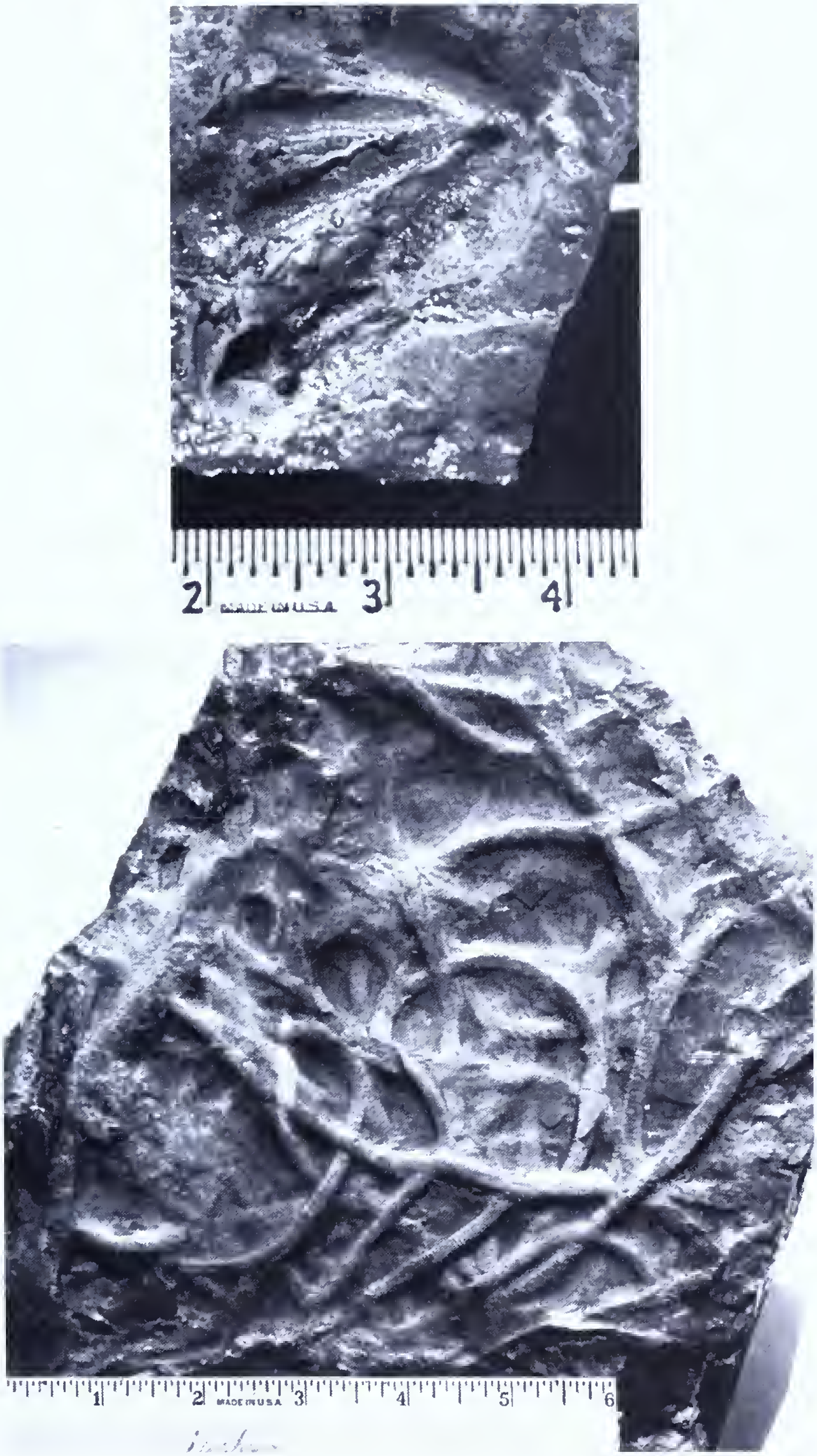

Figure 6. Two varieties of burrows from the Tuscarora Formation at Millerstown, Perry County. These are sole markings which occur on the undersides of quartzite beds. Scale in inches. (a) *Arthrophycus alleghenensis*, (b) *Fucoides alleghenensis*.

The best Tuscarora exposure is along U.S. Route 22-322 one mile (1.6 km) north of Millerstown (Figures 5, 7, 53, and 100). The upper 270 feet (82 m) of the Tuscarora is exposed at this locality, which is about half of the total thickness of the formation.

The thickness of the Tuscarora Formation in the Millerstown quadrangle ranges from approximately 550 feet (168 m) on Tuscarora Mountain to 700 feet (213 m) on Shade Mountain. Table 6 lists the thickness of the Tuscarora at nearby localities. An isopach map of the formation (Woodward, 1941) shows that it is an elongate, lens-shaped body of quartzite and sandstone which trends northeastward, approximately parallel to the present structural trend of the Appalachians. As shown on lithofacies and isopach maps (Cate, 1965) and cross sections (Folk, 1960), the Tuscarora thickens and coarsens eastward across the State and becomes the conglomeratic Shawangunk Formation in the vicinity of the Delaware River.

Formation Boundaries

Both the upper and lower contacts of the Tuscarora Formation are conformable and interbedded. The nature of the basal contact was discussed previously in the Juniata section. The contact with the overlying

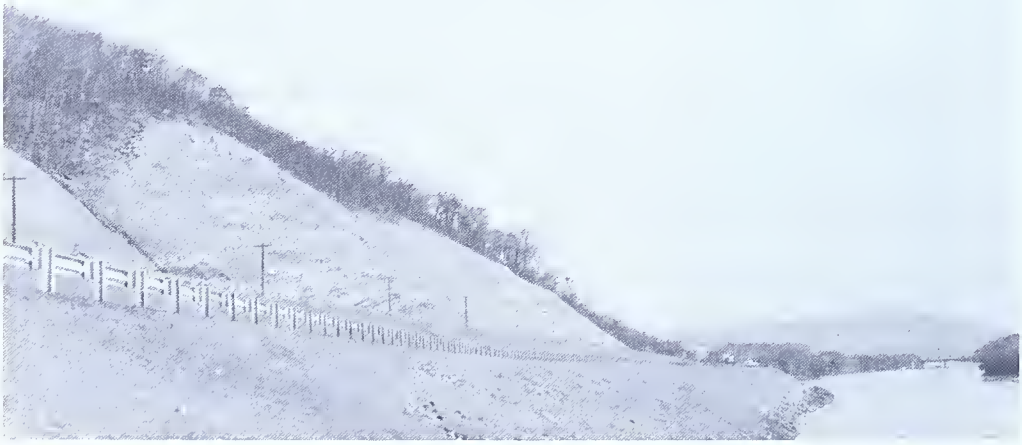

Figure 7. Silurian Tuscarora Formation exposed in Tuscarora Mountain anticline on the east side of the Juniata River a mile northwest of Millerstown, Perry County. Viewed from the north. Millerstown Silurian section begins with the lowest beds exposed on the upper bench, which carries the northbound lane of U.S. Route 22-322.

Table 6. *Thicknesses of the Tuscarora Formation in Central Pennsylvania*

Locality	Quadrangle (15′)	County	Thickness (feet)	Thickness (meters)	Source
Run Gap, Tuscarora Mountain	Loysville	Juniata, Perry	561	171	Miller, 1961*
Kishacoquillas Gap, Jacks Mountain	Lewistown	Mifflin	493	150	Horowitz, 1965*
Susquehanna Gap, Blue Mountain	Harrisburg	Cumberland, Perry	394	120	Dyson, 1967*
Ferster, Bottieger, and Shellenberger Gaps, Shade Mountain	Millerstown	Snyder	586	179	this report**

* Measured.

** Calculated from geologic map.

Rose Hill Formation is mapped at the top of the highest prominent light-gray quartzite bed. A few thin beds of Tuscarora lithology occur slightly higher in the section, and some shale and siltstone beds similar to those in the Rose Hill are present below this horizon. At the Millerstown Silurian section (Appendix I, locality 1) the base of the Rose Hill consists of greenish-gray argillaceous sandstone which forms a prominent ledge four feet (1.2 m) thick. This sandstone is probably the equivalent of the Castanea Sandstone, which is better developed to the northwest, and is reported to be 72 feet (22 m) thick in Kishacoquillas Gap in Jacks Mountain (Swartz, 1934).

Age

The Tuscarora Formation has been assigned to the Llandovery Series (Lower Silurian Series) by Berry and Boucot (1970). However, the absence of megafossils in this sequence led Yeakel (1959) to suggest that "It is impossible to establish time lines in the wedge of clastic sediments derived from the Taconic uplift in the central Appalachians. The obvious change in the depositional framework began with the Bald Eagle, but because this is based on physical evidence it need not necessarily correspond to the paleontologically established Ordovician-Silurian boundary." Cramer (1969) was able to obtain fossil spores and pollen from the shales in the upper part of the Tuscarora, and, on the basis of the phytoplankton assemblages, confirmed a later lower Llandovery age, equivalent to graptolite zones 18 through 20 (Cramer, personal commun., 1970).

Sedimentation

The coarseness and "cleanness" of the Tuscarora quartzites, and the presence of well-rounded quartz grains, suggest deposition in a relatively high energy environment. Most recent stratigraphic and sedimentological studies suggest that this environment was nonmarine and fluvial (Thomson, 1957; Yeakel, 1962; Horowitz, 1965; Smith, 1967). Evidence cited to support this interpretation includes tabular sets of crossbeds, consistent dip directions of the crossbeds, thin, lenticular siltstones and shales, irregular bedding surfaces, wide variation in grain size and bed thickness, abundant cut-and-fill structures, the presence of shale pebbles and current crescents, and the systematic decrease in maximum pebble size in the direction of crossbedding dip vectors.

Yeakel (1962) reported a mean dip azimuth of 322° from measurements of 6,753 crossbeds in the Tuscarora. This direction is parallel to the paleoslope direction as determined by independent criteria, including sand-shale ratios, thickness measurements, and the decrease in maximum pebble size. Thomson (1957) had detected similar paleocurrent directions in the Tuscarora-correlative Shawangunk and Green Pond Formations in New Jersey.

Smith (1969, 1970) suggested that systematic changes in ratios of bed forms in the Tuscarora in a northwesterly direction reflect a change in deposition from longitudinal to transverse stream channel bars down the paleoslope. This change probably coincides with a transition from an alluvial-fan to coastal-plain environment.

Folk (1960), in a study of the petrography of the Tuscarora in eastern West Virginia, concluded that it was deposited in a high-energy beach environment in that area. This interpretation is based largely on the rounding of the quartz grains, destruction of soft metamorphic rock fragments, winnowing of the silt and clay matrix, and sorting of the sand fraction. Folk (1960), Knight (1969) and Hartenstein (1967) show the Tuscarora intertonguing with marine sediments to the west, toward the Ohio border. Hartenstein (1967) and Knight (1969), in regional studies of the lower Silurian sandstones, observed that in western Pennsylvania the Tuscarora and Medina sandstones were deposited in a series of coalescing deltas and became progressively more marine westward. These sandstones grade laterally into, and are overlain by, fine-grained marine clastics and carbonates, thus showing a complete transition from nonmarine to marine environments across the State.

Most of the sedimentary structures cited above as evidence of fluvial deposition are present in the Tuscarora Formation at Millerstown. Sedimentary structures typical of recent beach deposits, primarily thick, parallel-laminated sands (Thompson, 1937), are notably lacking here. A comparison of the sediment and sedimentary structures on modern coastal beaches in Massachusetts and Delaware (see Kraft, 1968; Hayes, 1969) with the Tuscarora does not favor a beach interpretation for this formation in the Millerstown area. Thus the writers favor a fluvial (braided stream) origin for the Tuscarora at this locality.

Rose Hill Formation

Name and Extent

The name Rose Hill Formation was proposed by Swartz (1923) for "all the beds between the top of the Tuscarora and the bottom of the Keefer Sandstone in Maryland." The name has since been applied throughout the central Appalachians from Pennsylvania to eastern Tennessee. Throughout this region, the Rose Hill is generally included in the Clinton Group which comprises, in ascending order, the Rose Hill Formation, the Keefer Sandstone, and the Rochester Shale.

Two thin, hematitic sandstone units, referred to as "iron sandstones," occur in the Rose Hill in the Millerstown quadrangle. The lower iron sandstone is the Cabin Hill Member (Miller, 1961), and the upper is the Center Member (Swartz and Swartz, 1931). Iron-bearing sandstones occur in the Rose Hill throughout the Appalachians, but they vary in number, thickness, and stratigraphic position from one locality to another and are not generally correlative over long distances. Several of these iron sandstone units were given local names by early workers in this area. Figure 8 shows the stratigraphic position of these units, and the relationship of the earlier terminology to current usage.

The terms "lower shaly member," "middle shaly member," and "upper shaly member" are used informally to designate the intervals of the Rose Hill below, between, and above the iron sandstones.

Character

The Rose Hill Formation in the Millerstown area is predominantly light-olive-gray shale, with two grayish-red to reddish-black sandstone members (Millerstown Silurian section, Appendix I, locality 1). See Table 5 for the lithologic distribution of the Rose Hill at this locality.

The lower shaly member consists predominantly of medium-light-gray and light-olive-gray shale which is generally very finely silty, subwaxy, and fairly to poorly fissile. Approximately 20 percent of this unit contains interbedded light-olive-gray to medium-light-gray siltstone, which is slightly argillaceous and siliceous, thin to very thin bedded and ripple marked.

The middle shaly member is mainly shale and siltstone similar to the lower member, but locally it becomes slightly calcareous and fossiliferous.

The shales of the upper shaly member tend to be medium dark gray, are locally micaceous and calcareous, and contain a significant amount (approximately one-third) of interbedded limestone (Figure 9). The limestones are medium-light-gray to medium-dark-gray bioclastic calcarenites which are thin bedded, planar bedded, and locally pyritic. The skeletal material present usually consists of broken and unidentifiable shell fragments, but locally, well-preserved pelecypods, bryozoans, brachiopods, and trilobites are present. Specimens of the trilobite genera *Calymene, Liocalymene,* and *Dalmanites* have been identified in the upper shaly member at Millerstown.

The "iron sandstones" are dark-reddish-gray to blackish-red sandstone and sandy siltstone, with interbedded gray to red shales. The sand is very fine to coarse grained, subrounded to angular, and poorly sorted, with up to 20 percent hematitic clay matrix. Opaque mineral grains, predominantly pyrite and magnetite, are generally present in amounts less than 2 percent. These sandstones are irregularly thin to medium bedded, and commonly occupy lenses and laminae in the enclosing shales (Figure 10).

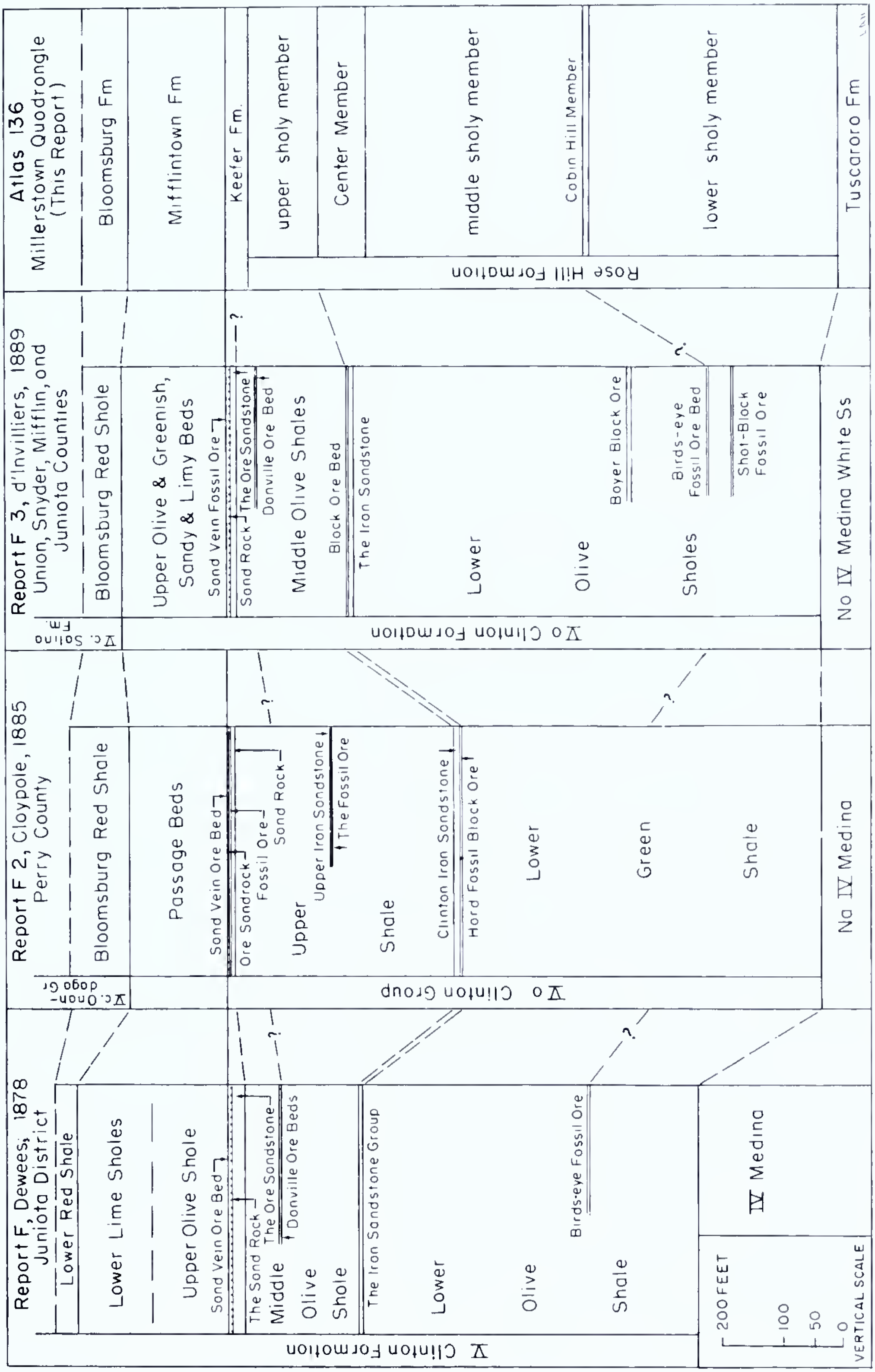

Figure 8. Stratigraphic terminology and suggested correlation of the Silurian iron-bearing strata in central Pennsylvania.

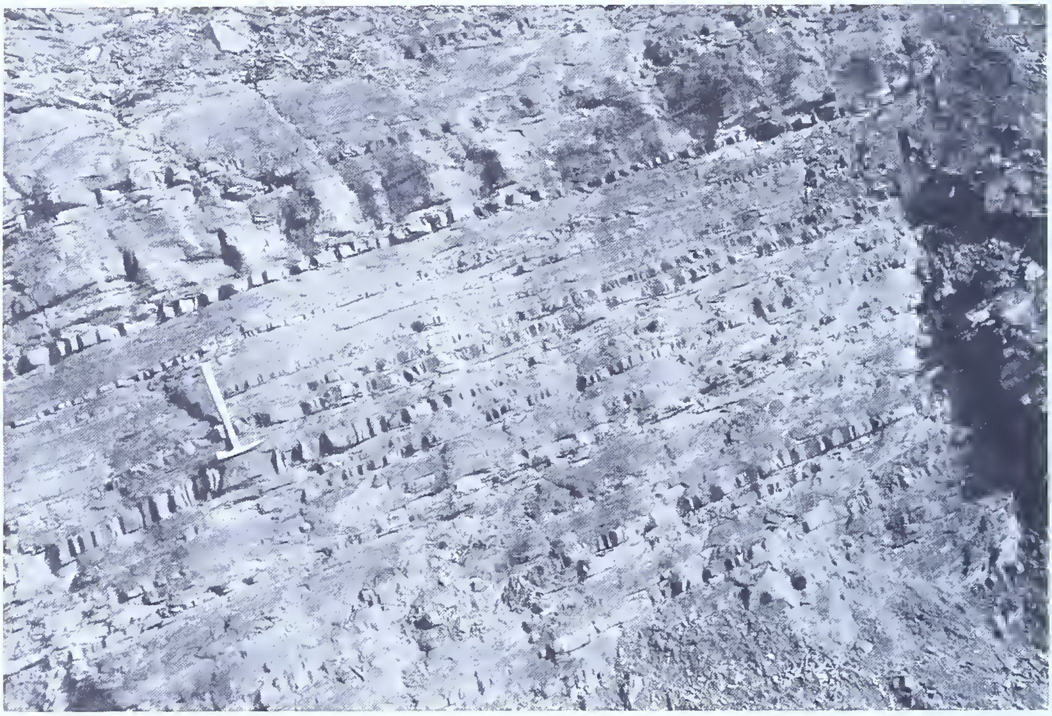

Figure 9. Upper shaly member of the Rose Hill Formation exposed on the north side of U.S. Route 22-322 northwest of Millerstown, Perry County (unit 96, Millerstown Silurian section, Appendix I, locality 1). The thin, blocky beds are medium-gray bioclastic calcarenitic limestone with interbedded gray shale.

Ripple marks and flaser bedding are common and a great variety of miscellaneous twiglike burrows and other sole markings are found where the sandstones overlie shale beds. Chemical analyses of composite samples from the iron sandstones in the Millerstown section (Appendix II) indicate a total iron content of 10.4 percent in the Cabin Hill Member and 8.2 percent in the Center Member.

Outcrop Area and Thickness

The Rose Hill Formation underlies the flanks of the two major anticlinal mountains in the quadrangle, Tuscarora Mountain and Shade Mountain. The iron sandstones of the Rose Hill are fairly resistant to erosion, and underlie secondary ridges which parallel the mountain crests on the south side of both Tuscarora Mountain and Shade Mountain (see frontispiece). In the hinge of the Tuscarora anticlinorium, east of the Juniata River, the Rose Hill forms Slaughterback Hill in which the iron sandstone members are locally well exposed.

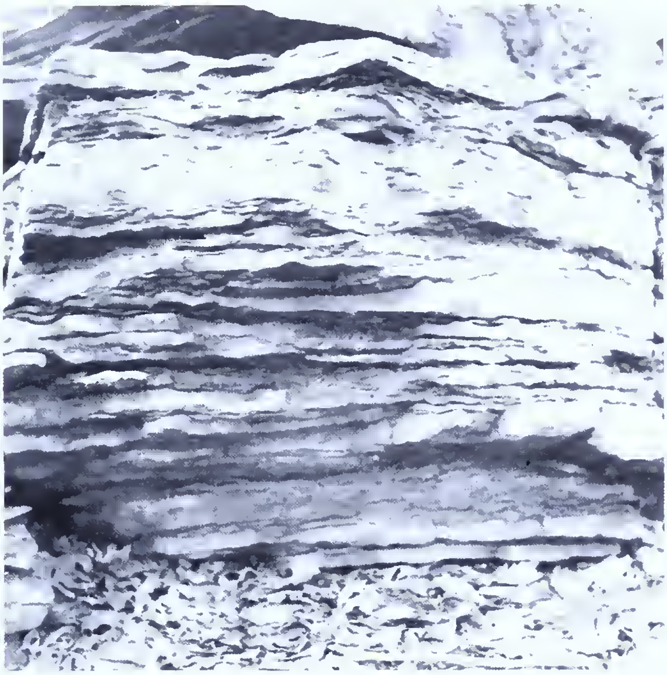

Figure 10. Flaser bedding in the lower iron sandstone, Cabin Hill Member of the Rose Hill Formation, exposed on Slaughterback Hill at Millerstown, Perry County.

The thickness of the members of the Rose Hill Formation at Millerstown are:

upper shaly member	116 feet	(35 m)
Center Member	79 feet	(24 m)
middle shaly member	360 feet	(110 m)
Cabin Hill Member	12½ feet	(4 m)
lower shaly member	379 feet	(116 m)
Total Rose Hill Formation	947 feet	(289 m)

The thickness of the Rose Hill in nearby areas is given in Table 7.

Formation Boundaries

The basal contact of the Rose Hill Formation is conformable, as discussed above. The upper contact of the Rose Hill (with the Keefer Formation) is conformable and transitional through the upper foot of unit 72 of the Rose Hill in the Millerstown section.

Age

The Rose Hill Formation was originally assigned to the Middle Silurian (basal Niagaran Series) on the basis of a fauna dominated by the brachiopod *Ceolospira hemispherica* and the trilobite *Calymene cres-*

Table 7. *Thickness Values for the Silurian Rose Hill Formation in Central Pennsylvania*

Locality	Quadrangle†	County	Thickness (feet)	Thickness (meters)	Source
Kishacoquillas Gap, Jacks Mountain	Lewistown	Mifflin	710 (partial)	216	Swartz, 1934*
Juniata River Gap, Mount Union	Mount Union 7½′	Mifflin	725	221	Swartz, 1934*
Skytop, Bald Eagle Mountain	Bellefonte	Centre	700	213	Swartz, 1955*
Susquehanna Gap, Blue Mountain	Harrisburg	Perry	506	154	Dyson, 1967*
Bear Lick, Cove Mountain	McConnellsburg 7½′	Fulton	650	198	Pierce, 1966*
none specified	Mifflintown	Juniata, Perry, Mifflin, and Snyder	850–900	259–274	Conlin and Hoskins, 1962**
none specified	Loysville	Perry	850–900	259–274	Miller, 1961***
Shade Mountain	Millerstown	Snyder	971	296	this report**
Slaughterback Hill	Millerstown	Juniata, Perry	947	289	this report*

* Measured section.

** Estimated thickness.

***Determined from composite measurements.

† Refers to 15-minute quadrangle unless otherwise stated.

apensis (Swartz, 1923). The microfossils found by Cramer (1969) in the Rose Hill at Millerstown confirm an upper Llandovery age for the formation, as shown by Berry and Boucot (1970).

Sedimentation

The combination of light-olive-gray shales containing ripple-marked silt, flaser bedding, and trilobites, bioclastic limestones which have a pelecypod, bryozoan, and brachiopod fauna, and red, poorly sorted sandstones observed in the Rose Hill suggest that it was deposited in littoral to epineritic marine environments. The ripple marks and flaser bedding indicate water depths above wave base, probably in the intertidal zone. The burrows in the sandstones also suggest shallow, although not necessarily intertidal water, and the red color of the sandstones indicates that oxidizing conditions prevailed. The upward increase in calcium carbonate and fossil content in the formation suggests that the water became clearer, and perhaps slightly deeper, as sedimentation proceeded.

Smith (1968) and Smith and Saunders (1970) discuss the Rose Hill Formation at Schuylkill Gap, some 60 miles (97 km) east of Millerstown, and suggest that there the Rose Hill is a littoral (tidal-flat and lagoonal) deposit, and that open-marine conditions prevailed to the northwest. Folk (1960) and Pierce (1966) conclude that the Rose Hill in south-central Pennsylvania and northeastern West Virginia was deposited in a neritic marine to brackish-water environment. The inferred paleogeography for the Appalachian geosyncline during the deposition of the Rose Hill is that of a shallow shelf or epicontinental sea, bordered on the east by a low-lying source area, with a broad tidal-flat and lagoonal area between the two.

The iron sandstones indicate times when coarser sediment was being supplied to the area, in an environment which was probably similar to that which prevailed when the shales and claystones were accumulating. Folk (1960) suggests that the iron sandstones were deposited in shallow, nearshore marine environments, and that the bulk of the iron was precipitated close to shore, under oxidizing conditions, near the mouths of large rivers. Hunter (1970) elaborated on the origin of the iron, and concluded that most of the iron was precipitated as oolitic coatings on sand grains prior to final deposition, and later recrystallized or dissolved and re-precipitated as interstitial hematite.

Miller and Folk (1955) observed that the red intervals in the Rose Hill and other formations consistently contain magnetite and ilmenite, while these minerals are absent from nonred strata in these units, and are also absent from nonred zones within the red beds. They conclude that the formation of red beds depends primarily on the presence of an igneous or metamorphic source which supplies detrital magnetite and ilmenite and is only indirectly dependent on climate or environment of deposition. Magnetite is a common constituent of the Rose Hill iron sandstones, but no ilmenite was detected in samples from the Millerstown quadrangle.

Keefer Formation

Name and Extent

The earliest available reference to the Keefer is that of Ulrich (1911), who does not cite any type locality but rather implies that the term had been in general use prior to that time. The name "Keefer" was derived from Keefer Mountain in Franklin County, Pennsylvania, where the formation is 25 feet thick (Swartz, 1923). The Keefer sandstone has been considered the basal member of the McKenzie Formation (Stose and Swartz, 1912), and of the Mifflintown Formation (Miller, 1961). However, because the Keefer is a distinct, mappable unit in central Pennsylvania, DeWitt and Colton (1964) proposed that it be considered a separate formation. Therefore, in this report, the name "Keefer Formation" refers to the sandstone unit which overlies the Rose Hill Formation and underlies the Mifflintown Formation (in the restricted sense). The local correlation of the Keefer Formation is shown in Plate 4.

The Keefer is present throughout central and south-central Pennsylvania, and extends into western Maryland and northeastern West Virginia.

Character

The Keefer Formation consists predominantly of silicified, fossiliferous sandstone, hematitic, oolitic sandstone, and minor intervals of shale. (See Figures 11 and 12, Table 5, and the measured section description in Appendix I.) The sandstone is light gray to dark gray, commonly mottled, and weathers to very light gray or white. It is very fine to coarse grained, silty, locally conglomeratic, very thin to very thick bedded and crossbedded, and commonly contains ripple marks, burrows, occasional flaser bedding, and shale pebbles. The detrital grains are quartz, and (rarely) calcite, quartzite, and fine-grained rock fragments. The grain size, shape, and sorting are extremely variable, with some poorly sorted beds of silt to very coarse sand adjacent to well-sorted beds of very fine or fine-grained sand. Grain shape ranges from well rounded to angular, but much of the present angularity of the grains may be due to diagenetic precipitation of silica on grains which were initially somewhat better rounded. The cement is mostly silica (generally crystallized in optical continuity with the detrital quartz grains), and, to a much lesser extent, calcite. The sand ordinarily has less than 5 percent clay matrix, probably illite-sericite. Hematite, limonite, and pyrite are common in

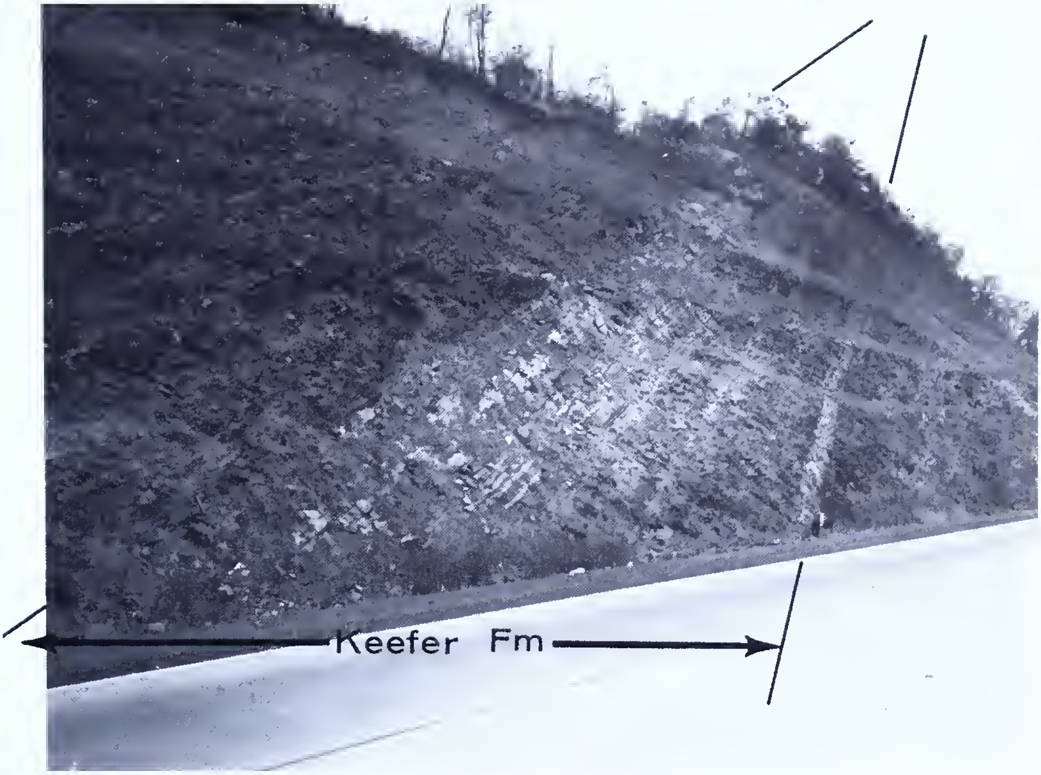

Figure 11. Keefer Formation exposed on north side of U.S. Route 22-322 northwest of Millerstown, Perry County, in the upper segment of the Millerstown Silurian section (Appendix I, locality 1). Field assistant stands at the base, and hammer marks the position of the top of the Keefer Formation.

the matrix, but the iron concentration probably does not exceed 5 percent in most beds. Tourmaline, zircon, and other accessory minerals are present in trace amounts. Some of the sandstone beds are fossiliferous, bearing crinoid stems, brachiopods, and various mollusc shells. Abundant *Skolithos* burrows were found in the Keefer on the north flank of Tuscarora Mountain near the west edge of the quadrangle, but were not found elsewhere in the quadrangle.

Thin zones of fair to good porosity and permeability are present in some Keefer sandstone outcrops, and may be present in the subsurface. However, most of the original porosity has been destroyed by cementation, and wells drilled into the Keefer usually encounter little porosity.

The hematitic, oolitic sandstone is dark gray to blackish red, very fine to medium grained, medium to thin bedded, and crossbedded. This sandstone appears to have been originally cemented with calcite that was

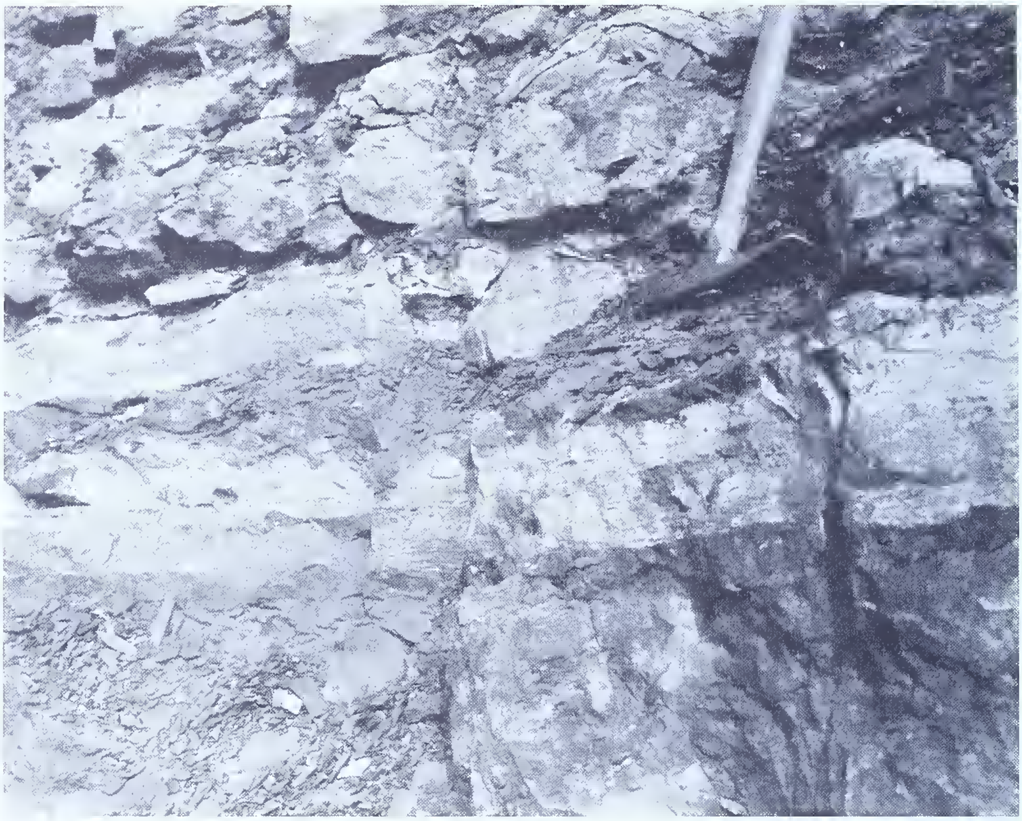

Figure 12. Detail of Keefer sandstone in the Millerstown Silurian section.

subsequently replaced by hematite. A thin (generally 1 to 2 feet, .3 to .6 m thick) hematitic zone near the top, called the Sand Vein Ore Bed, was mined extensively throughout the Valley and Ridge province during the nineteenth century. Because of this mineable, hematitic zone, the Keefer was locally called the "Ore Sandstone" (Dewees, 1878, and d'Invilliers, 1891) and the "Ore Sandrock" (Claypole, 1891). (See Figure 8.)

The shale and claystone are medium dark gray, silty, generally noncalcareous, poorly fissile, and pyritic. These shales are similar to those in the Rose Hill and Mifflintown Formations.

Outcrop Area and Thickness

The Keefer Formation is a fairly resistant unit which forms small terraces on the dip slopes of ridges underlain by Tuscarora quartzite and the Center Member of the Rose Hill Formation. Good exposures can generally be found wherever the Rose Hill ridge is cut by transverse stream valleys. The Keefer is one of the more traceable units in the quadrangle because of its distinctive topographic expression and lithology (Figure 13).

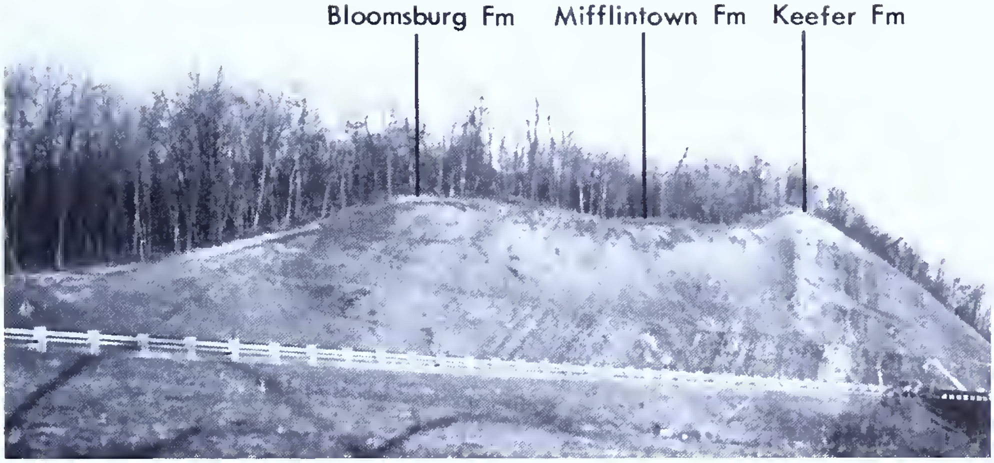

Figure 13. Outcrop of the Keefer, Mifflintown, and Bloomsburg Formations at the north end of the Millerstown Silurian section, showing the typical topographic expression of these units.

The Keefer sandstone is 38 feet (12 m) thick in the Millerstown Silurian section. Regionally, the Keefer is a tabular body of sandstone which maintains a fairly constant thickness over a considerable area in central Pennsylvania (Table 8). The strikingly constant thickness of this blanket of sand has been documented by Luttrell (1968), whose measured sections show that the Keefer sandstone ranges in thickness from one to twenty meters over an area of at least 10,000 square miles (25,900 sq. km).

Formation Boundaries

The Keefer Formation lies with no apparent disconformity upon the upper shaly member of the Rose Hill Formation. The top of the Keefer is a sharp conformable or paraconformable contact.

Age

The Keefer is medial Middle Silurian (Niagaran) in age (Swartz, 1923; Swartz and others, 1942), and is the oldest formation in the Wenlock Series of Berry and Boucot (1970).

Sedimentation

The occurrence of brachiopod, crinoid, and mollusc shells in the Keefer indicates that it was deposited in a shallow-water (littoral to epineritic) marine environment. An abundant supply of sediment and

Table 8. *Thickness Values for the Keefer Sandstone in Central Pennsylvania*

Locality	Quadrangle*	County	Thickness (feet)	(meters)	Source
Keefer Mountain	Hancock 7½′	Franklin	25	7.6	C. K. Swartz, 1923
Mount Union	Mt. Union 7½′	Mifflin	47	14.3	F. M. Swartz, 1934
Kishacoquillas Gap	Lewistown	Mifflin	55	16.8	F. M. Swartz, 1934
Mifflintown	Mifflintown	Juniata	34	10.4	Miller, 1961
Burnt Ridge	Loysville	Perry	50	15.2	Miller, 1961
Susquehanna Gap	Harrisburg	Perry	24	7.3	Dyson, 1967 (may be partial section)
Wardville	Millerstown	Perry	40	12.2	Robinson, 1957
Millerstown	Millerstown	Juniata	38	11.6	this report

* Refers to 15-minute quadrangle unless otherwise stated.

fairly rapid deposition is suggested by the generally poor sorting and variable rounding of the quartz grains. The regionally thin, tabular form of the Keefer sandstone suggests deposition along a laterally migrating shoreline. The sharp upper contact of the formation, in contrast to the conformable, possibly gradational base, suggests an interruption of sedimentation at the end of the Keefer deposition. The low clay content of the sandstones, the local occurrence of shale clasts and small pebbles, and the presence of beds of well-rounded and sorted sand and the occasional very well rounded quartz grains indicate a proximity to the surf zone. The significance of interbedded thin, medium, and thick sandstone beds is not clear, except that it implies deposition by processes which were both intermittent and variable. The interbedded shales represent periods of quiet-water deposition, either in a sheltered lagoonal area or offshore.

Folk (1960) suggested that the Keefer was deposited in a lagoon-beach-barrier complex which separated the marine shale environment of the Rose Hill from a lagoonal area where the shale of the Rochester (Mifflintown) Formation was being deposited.

Luttrell (1968) studied the Keefer Formation across central Pennsylvania, and concluded that it is a regressive marine deposit in which much of the rounding and sorting of the sand was accomplished by eolian processes on the coastal plain. Luttrell calculated a water depth ranging from 0 to 100 feet (30 m) above a sea floor which sloped to the northwest at a rate of one to two feet per mile (0.18 to 0.36 m per km).

The character of the Keefer sandstone, as described above, is compatible with this interpretation, i.e., deposition along a prograding shoreline during a time of marine regression. The nonmarine sediments associated with this regression are represented by the conglomerates of the Shawangunk Formation in the eastern part of the State (Folk, 1962, p. 553). The regression which allowed the shoreline to migrate across the area was apparently followed by a rapid transgression which left little recognizable sedimentary record, except for the sharp, planar contact at the top of the Keefer.

Mifflintown Formation

Name and Extent

The name "Mifflintown Formation" was proposed (Arndt and others, 1959) and defined (Miller, 1961) to embrace two rather similar shale and limestone units, the Rochester and McKenzie Formations, and the underlying Keefer Sandstone. The Rochester and McKenzie Formations are mapped in central New York State and in western Maryland. They are not lithologically distinct in central Pennsylvania, and can generally be differentiated there only on the basis of ostracod faunal zones (Swartz, 1934; Cloos, 1951). The Keefer sandstone is sufficiently distinguishable in the Millerstown area to be mapped as a separate formation. The Mifflintown is therefore redefined to include only the strata overlying the Keefer Formation and underlying the Bloomsburg Formation.

The Mifflintown Formation extends throughout the Valley and Ridge province of central Pennsylvania (except for the Great Valley Section), from the Cumberland area in Maryland (DeWitt and Colton, 1964; DeWitt, 1971) northeastward at least as far as the Susquehanna River. Farther east, the upper beds of the Mifflintown Formation are replaced by the red sandstones and shales of the overlying Bloomsburg Formation (Swartz, 1957). In the Delaware Valley area, the entire stratigraphic interval between the Upper Ordovician Martinsburg Formation and the Bloomsburg is replaced by the sandstone and conglomerate of the Shawangunk Formation (Epstein and Epstein, 1969).

Character

The Mifflintown Formation consists of interbedded shale (59 percent), and limestone (37 percent) with minor siltstone beds (4 percent) (see Figures 13 and 14 and Table 5). The shales are dark gray, silty, and calcareous, and have a fair to rather poor fissility. In the lower part of the formation they are similar to those in the upper shaly member of the underlying Rose Hill Formation.

The limestones are medium to dark gray, bioclastic, pelletal, microcrystalline, locally oolitic, medium to thin bedded, and planar bedded. They are predominantly bioclastic calcisiltite, composed of silt-size calcite grains and disarticulated ostracod fragments. These limestones contain as much as 20 percent quartz grains, in the form of very fine grained, subangular sand and silt, which has normal optical extinction and generally "floats" in a matrix of calcite silt. Pyrite, limonite, carbonaceous matter, and rare crystalline hematite are present in trace amounts. Some of the limestone beds have up to 10 percent vuggy and intergranular porosity, and locally there are traces of oil staining. A number of the beds are intraformational limestone breccia, composed of subangular to rounded fragments of micritic and pelletal calcisiltite in a matrix of pelletal and bioclastic (ostracodal) calcisiltite. At Mifflintown these breccias mark the lower 20 feet (7 m) of the upper (McKenzie) Member (Miller, 1961), but they do not appear to maintain the same stratigraphic position at Millerstown.

The siltstones are medium to medium dark gray, argillaceous, calcareous, and locally gradational with the enclosing shale beds. Flaser bedding (micro cross lamination) is locally present.

Typical Mifflintown lithology is shown in Figure 14, a detailed description of the unit is presented in Appendix I, and a chemical analysis is given in Appendix II.

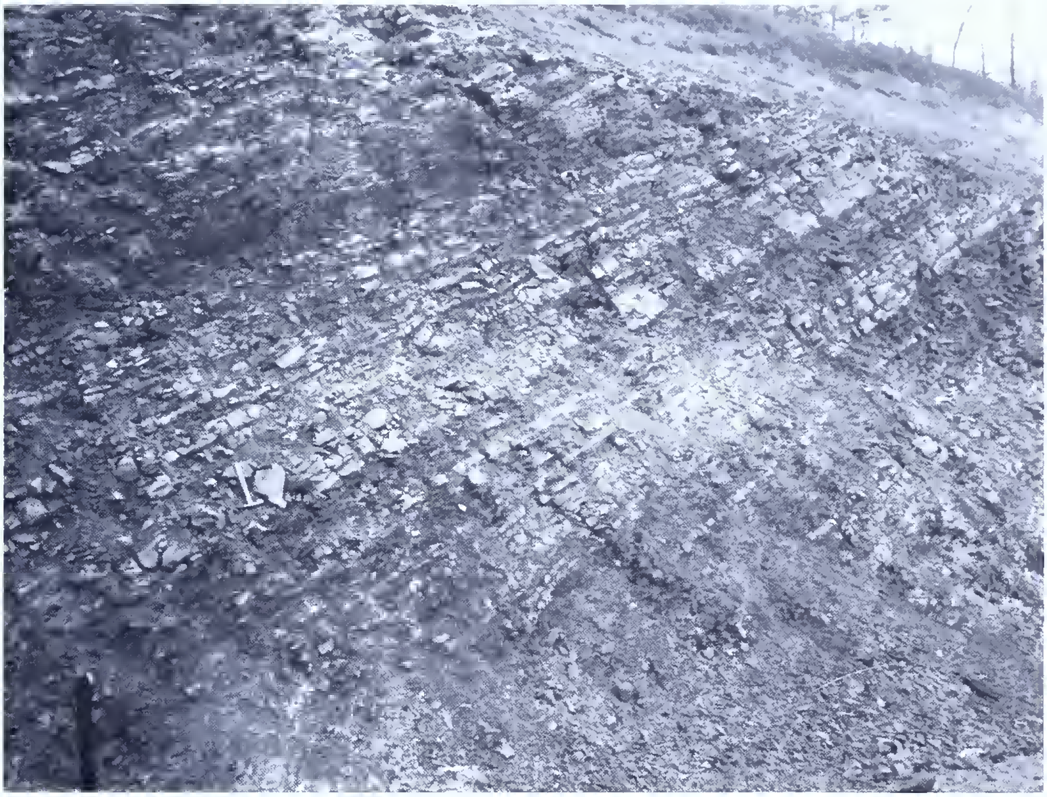

Figure 14. Mifflintown Formation exposed in the Millerstown Silurian section (Appendix I, locality 1). Hammer lies at top of unit 130 in the measured section.

Outcrop Area and Thickness

The Mifflintown Formation is a relatively nonresistant unit, and underlies a slight topographic swale between the Keefer Formation and the lowest Bloomsburg beds (Figure 13). Cultivated fields generally extend uphill to the Keefer sandstone outcrop at the base of the Mifflintown Formation. The only complete exposure of the formation in the quadrangle is on U.S. Route 22-322, two miles (3.2 km) north of Millerstown.

The Mifflintown is 159 feet (48 m) thick at Millerstown, the least thickness reported from central Pennsylvania (Table 9). An isopach map drawn from the data in Table 9 shows a consistent regional northeastward thinning from Bedford County to the Millerstown area. Isopach lines trend northwestward across the structural grain of the Valley and Ridge province, in striking contrast to those of most of the other mid-Paleozoic formations.

Table 9. *Thickness Values for the Mifflintown Formation (Rochester and McKenzie Members, Undivided) in Central Pennsylvania and Adjacent Areas*

Locality	Quadrangle*	County	Thickness (feet)	Thickness (meters)	Source
Granville Run, Blue Mountain	Lewistown	Mifflin	213	65	Swartz, 1934
Lewistown (east)	Lewistown	Mifflin	240	73	Swartz, 1934
Mount Union	Mt. Union 7½′	Mifflin	395	120	Swartz, 1934
Loysburg Gap	Everett	Bedford	428	130	Swartz, 1934
Mifflintown	Mifflintown	Juniata	264	80	Miller, 1961
Millerstown	Millerstown	Juniata	159	48	this report
Lakemont, Pa.	Altoona 7½′	Blair	360	110	Swartz, 1935
Cumberland, Md.	Frostburg	Allegany	329	100	Swartz, 1935

* Refers to 15-minute quadrangle unless otherwise stated.

Formation Boundaries

Both the upper and lower contacts of the Mifflintown Formation are sharp and conformable. The basal contact was described above, and the upper contact is an abrupt change from olive-gray shale to the grayish-red sandstone of the Bloomsburg Formation.

Age

The Mifflintown Formation is of middle and upper Niagaran age (Middle Silurian) (Swartz, 1933, 1934, 1935), and correlates with the Wenlock standard series (Berry and Boucot, 1970). Swartz (1934) reported that there are two distinct faunal zones present in this interval in the Mount Union area, based on ostracod assemblages. The lower zone is characterized by the ostracod *Drepanellina clarki,* and the upper zone by the brachiopod *Whitfieldella marylandica.* A sharp faunal break at the top of the *Drepanellina clarki* zone marks the horizon which correlates with the contact of the Rochester and McKenzie Formations (Swartz, 1934, p. 132).

Sedimentation

The Mifflintown Formation is an offshore, neritic marine deposit, as shown by the presence of planar-bedded fossiliferous limestone beds and marine fossils in the shales. The alternation of limestone and shale beds indicates an environment where the water was periodically very muddy. The presence of carbonaceous shale near the middle of the formation (unit 9) and occasional pyrite grains through the upper half indicates periods of restricted circulation, enabling reducing conditions to prevail. The oolites suggest proximity to an area of strongly agitated, shallow water, such as a lagoon or broad tidal flat. The intraclasts and intraformational limestone breccias point to shallow water conditions, because these form by disruption and resedimentation of semiconsolidated lime mud within reach of storm waves.

Folk (1962) suggested that the area was offshore from a low-lying coastal plain, and that streams on the coastal plain supplied the abundant clay in times of flood. The lowered salinity which would accompany this inflow of fresh water may account for the high concentration of ostracod shells in beds which lack other marine forms.

Bloomsburg Formation

Name and Extent

The name "Bloomsburg Formation" was proposed by White (1883) for a thick, westward-thinning wedge of red siltstone, sandstone, and silty claystone which occurs from southeastern New York to western Virginia. The formation was named for exposures in the city of Bloomsburg, some 45 miles (72 km) northeast of Millerstown in Columbia County, Pennsylvania.

Character

The Bloomsburg Formation is primarily a red shale and claystone unit, with two intervals of red sandstones, one at the base and the other near the top (Table 5).

The claystones are grayish red, pure to very finely silty, and break with a characteristic blocky or splintery fracture. The bedding is thick and planar, but usually so indistinct that it may be confused with poorly developed cleavage (Figure 15). The claystones are locally fossiliferous, and Hoskins (1961) identified *Lingula,* fish scales, foraminifera, and several species of ostracods in them.

The sandstones are grayish red to grayish brown, fine and very fine grained, silty, argillaceous, hematitic (Van Houten, 1968), poorly sorted, medium and thin bedded, planar bedded, slightly friable, and slightly porous. They are mostly hematitic subgraywackes, which average from 70 to 75 percent quartz sand and silt, 20 percent hematitic clay, 5 percent clay clasts and fine-grained rock fragments, less than 1 percent opaque mineral grains, and generally 5 to 10 percent porosity. The upper sandstone tends to be slightly finer grained than the lower. A few thin, nonred (medium-light-gray to buff), fine- to medium-grained, porous sandstone beds occur in the upper part of the Bloomsburg in the valley south of Slim Valley Ridge near Bunkertown.

The basal sandstone interval of the Bloomsburg at Millerstown is described in Appendix I (locality 1), the claystones in the Bloomsburg at Beavertown are described in Hoskins (1961, locality 6), and a chemical analysis of the claystone is presented in Appendix II. A preliminary evaluation of the clays is given in Appendix III.

Outcrop Area and Thickness

The Bloomsburg Formation occurs in the valleys surrounding Shade and Tuscarora Mountains and Slim Valley Ridge. The basal and upper sandstone intervals usually support a slight topographic rise, such as is shown in Figure 13. The characteristic reddish-brown soils which develop over the Bloomsburg claystones and the more resistant nature of the sandstone intervals permit fairly accurate mapping of the Bloomsburg contacts in covered areas. The most complete Bloomsburg exposure in the quadrangle is in the Glen-Gery quarries in Beaver Township on the north side of Shade Mountain.

The Bloomsburg is 450 feet (137 m) thick at Beavertown (Hoskins, 1961) and is estimated to be 480 feet (146 m) thick at Millerstown. Iso-

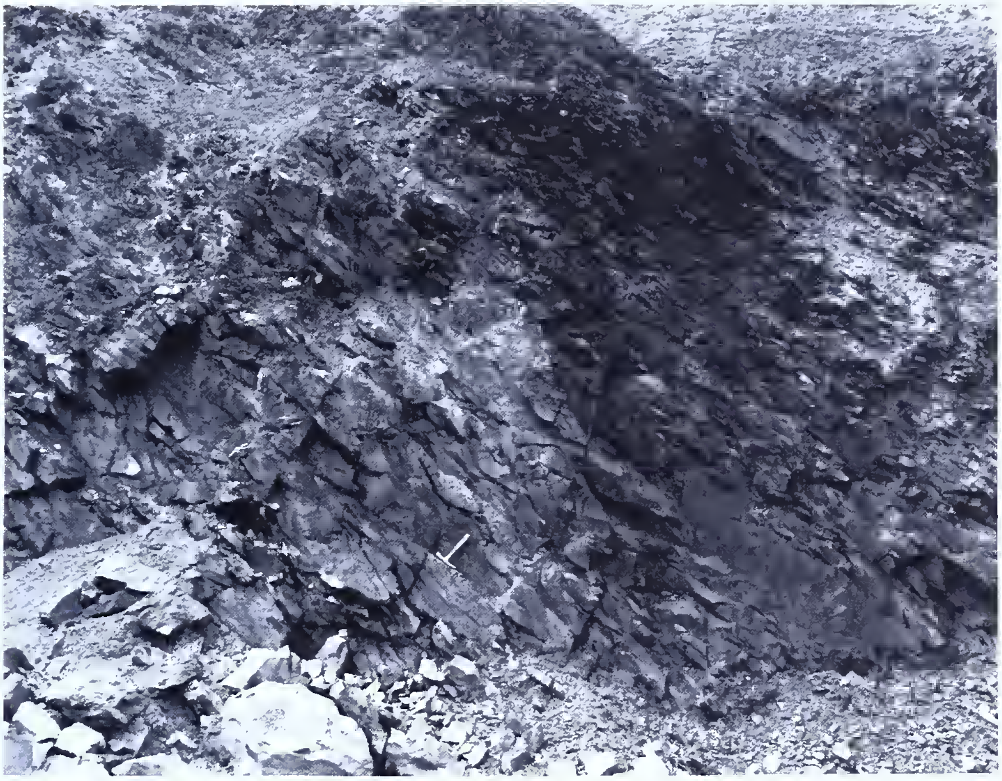

Figure 15. North-dipping Bloomsburg Formation exposed in the Glen-Gery Corporation quarry on Kern Run, 0.75 mile south of Beavertown, Snyder County.

pach maps for the Bloomsburg in central Pennsylvania (Hoskins, 1961; Wood and others, 1969) show a pronounced eastward and southeastward thickening, at a rate of approximately 25 feet per mile (4.8 m per km) (Table 10). Faunal zones within the Bloomsburg indicate that it thickens partly at the expense of the enclosing Mifflintown and Wills Creek Formations (Swartz, 1934).

Formation Boundaries

Both the upper and lower contacts of the Bloomsburg are conformable. The base of the formation can be seen near the top of the Millerstown Silurian section, on U.S. Route 22-322 two miles (3.2 km) north of Millerstown, where there is a sharp contrast between the light-olive-gray shale of the Mifflintown and the grayish-red sandstone of the Bloomsburg. The top of the Bloomsburg can be seen at the Beavertown locality, where the contact with the overlying Wills Creek is exposed in a creek bank 40 feet (12 m) north of the northernmost quarry.

Table 10. *Thickness Values for the Bloomsburg Formation at Selected Localities in Central Pennsylvania*

Locality	Quadrangle	County	Thickness (feet)	Thickness (meters)	Source
Bedford	Bedford and Hyndman 15′	Bedford	43	13	Hoskins, 1961
Mount Union	Mount Union 7½′	Mifflin	155	47	Swartz, 1934
Lewistown	Lewistown 7½′	Mifflin	309	94	Hoskins, 1961
Beavertown	Millerstown 15′	Snyder	450	137	Hoskins, 1961
Bloomsburg	Bloomsburg 7½′	Columbia	498	152	Hoskins, 1961
New Ringgold	Pottsville 15′	Schuylkill	1,815	553	Swartz and Swartz, 1941
Lehigh Gap	Lehighton 7½′	Carbon	2,000	610	Swartz and Swartz, 1941

Age

The Bloomsburg is a time-transgressive unit. The deposition of sediments which now comprise the Bloomsburg began in late Niagaran (Middle Silurian) time and continued well into Cayugan (Upper Silurian) time. According to Berry and Boucot (1970), the top of the Bloomsburg becomes progressively younger toward the east.

Sedimentation

The fauna in the Bloomsburg claystones consists of only a few specimens of most of the major phyla, except for the ostracods which are present in large numbers of individuals but very few species (Hoskins, 1961). Such a distribution of organisms is characteristic of brackish-water conditions in modern environments. A shallow water depth is indicated because ostracods occur at depths of less than 90 feet (27 m) (Elias, 1937) and *Lingula* live above a depth of 60 feet (18 m) (Schuchert, 1911). These features indicate that the Bloomsburg Formation is a paralic (marginal marine) deposit which formed in a nearshore brackish-water environment, such as a bay or estuary where salinity was lowered by the inflow of fresh water from rivers on the adjacent coastal plain, or as a distal (offshore) area of a delta complex (DeWindt, 1973). Lagoonal conditions may have prevailed at times (Swartz, 1946; Hoskins and Conlin, 1958; Wood and others, 1969).

The rather poorly sorted sandstones at the base suggest rapid deposition with a minimum of wave action. The sand was derived from a source terrain in which both igneous and metamorphic rocks were exposed (Hoskins, 1961).

Folk (1960) suggested that the red color formed when iron, which was being carried in solution by the rivers draining the source area, was precipitated upon encountering the more saline marine waters. On the other hand, Hoskins (1961) suggested that the red color was primary, and had developed in a warm, humid environment during weathering of the crystalline source rock, and was preserved by fairly rapid deposition and burial. The inference is that the supply of clay was abundant and continuous, muddying the water, restricting the kinds of organisms which could survive, and isolating the sediment from the seawater before the iron could be reduced and the red color lost.

To the east, in the area between the Susquehanna and Delaware Rivers, the Bloomsburg is a nonmarine fluvial deposit, the product of sedimentation in meandering rivers and on floodplains (Smith, 1967). The Bloomsburg in the Millerstown quadrangle is apparently transitional between this eastern, continental facies and the predominantly marine carbonates, shales, and marls which are present farther west (Alling and Briggs, 1961).

Wills Creek Formation

Name and Extent

The name Wills Creek was first applied by Uhler (1905) to a calcareous shale sequence exposed along Wills Creek near Cumberland, Maryland. These rocks had previously been included in Unit V, the Scalent gray marl, by the First Geological Survey of Pennsylvania (Rogers, 1858). The Wills Creek Formation is now recognized throughout the Valley and Ridge province from central Pennsylvania to western Virginia.

Character

The Wills Creek Formation consists of a number of related rock types that are extensively interbedded: silty claystone, claystone, calcareous shale, argillaceous limestone, and fine-grained calcareous sandstone. The color of the shale and claystone is somewhat variable, but usually is light olive, yellowish, or greenish gray, light gray, or grayish red. In the lower part of the formation, the colors are interlayered, giving a variegated appearance to the rock. Frequently, the red and nonred layers are repeated in a series of interbedded cycles.

Interbedding occurs on several scales. On a gross scale, the Wills Creek is divisible into two similar (informal) members. The lower parts of each member consist of laminated to very thin bedded calcareous shale and argillaceous limestone. The upper parts are coarser grained, predominantly very thin bedded calcareous siltstones and sandstones, which are relatively resistant to erosion.

Thick and thin interbedding occurs between the claystones and limestones in cyclic fashion. The lower parts of the cycles contain interbedded, thin-bedded (1/4 to 1/2 inch or 0.6 to 1.3 cm), light-olive-gray claystone and light-gray, laminated to very thin bedded limestone. The upper parts of the cycles consist only of noncalcareous claystone, usually light olive gray, occasionally grayish red, which locally contains calcareous nodules. These cycles range from 4 to 12 feet (1.2 to 3.7 m) in thickness. The transition from the lower to the upper part of each cycle is gradational over an interval of approximately 4 to 6 inches (10 to 15 cm), but the transition to the lower part of the next cycle is more abrupt, occurring over an interval of 1 to 2 inches (2.5 to 5 cm).

The sandstones are also interbedded with other lithologies. Some are light-gray, medium- to thick-bedded, fine-grained calcareous sandstones. Others occur as light-olive-gray to light-gray, very thin bedded, very fine to fine-grained sandstone lenses which have what approaches a flaser bedding, interbedded with light-olive-gray, very thin bedded siltstone and silty claystone.

Occasional medium-gray, medium- to thick-bedded limestones occur throughout the formation.

Outcrop Area and Thickness

The Wills Creek Formation underlies broad valleys off the flanks of both Tuscarora and Shade Mountains, including the valley of the Juniata River north of Tuscarora Mountain. Because these valleys are extensively farmed, outcrops are few and occur only in some stream banks and roadcuts (Figure 16). The subdivision of the Wills Creek into upper and lower members follows that used in the adjacent Loysville and Mifflintown quadrangles. These members are traceable across the quadrangle using two low topographic ridges which develop at the top of each member, and persist for several miles apparently at the same stratigraphic level.

No accurate determination of the thickness of the Wills Creek is available from the limited exposures in the quadrangle. The thickness is estimated to be between 600 and 800 feet (183 to 244 m). Thickness values for the Wills Creek Formation in central Pennsylvania are presented in Table 11 and range from 505 to 800 feet (154 to 244 m).

Formation Boundaries

The basal contact of the Wills Creek is conformable and is exposed in the bank of Kern Run, north of the Glen-Gery quarries, a half mile south of Beavertown in Snyder County. The contact of the Wills Creek

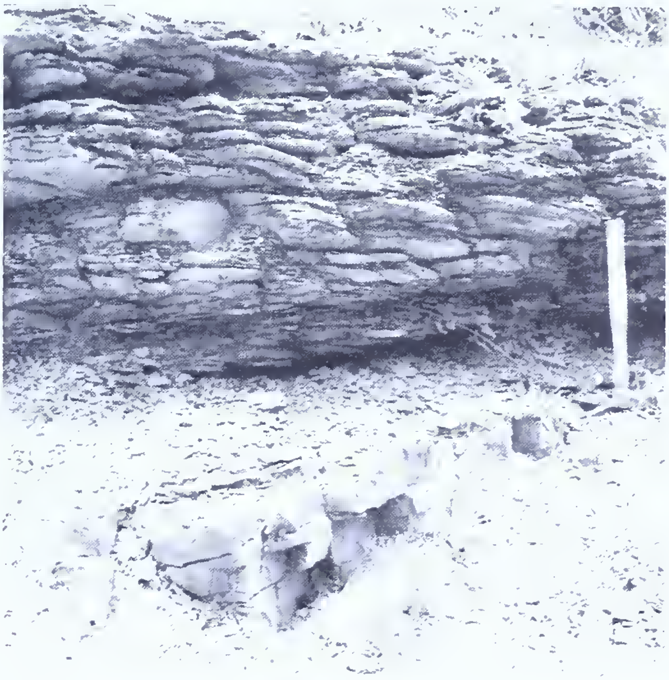

Figure 16. Outcrop of Wills Creek Formation in bank of small stream about 1 mile east of Bunkertown, Fayette Township, Juniata County.

Table 11. *Thickness Values for the Wills Creek Formation in Central Pennsylvania*

Locality	Quadrangle*	County	Thickness (feet)	Thickness (meters)	Source
Ickesburg, Andersonburg, Landisburg	Loysville	Perry	625	191	Miller, 1961
none specified	Mifflintown	Juniata	550–650	168–198	Conlin and Hoskins, 1962
northwest	New Bloomfield	Perry	600	183	Dyson, 1967
Susquehanna Gap	Harrisburg	Perry	zero (formation absent)		Dyson, 1967
Lewistown (east)	Lewistown 7½′	Mifflin	505	154	Swartz, 1934
none specified	Sunbury	Snyder	600	183	Hoskins, 1969, personal commun.
Pfoutz Valley, Little Pfoutz Valley	Millerstown	Perry	800	244	this report (calculated)

* Refers to 15-minute quadrangle unless otherwise stated.

with the overlying Tonoloway Formation is not exposed in the quadrangle, but, judging from exposures in adjacent quadrangles and topographic expression, the two formations are interbedded.

Age

The Wills Creek Formation is considered to be Upper Silurian (Cayugan) in age (Swartz and others, 1942), and correlates with the upper part of the Ludlow Series and the lower part of the Pridoli Series of the Standard Silurian Section (Berry and Boucot, 1970). This age assignment is based on a varied fauna which includes ostracods, eurypterids, trilobites, corals, and brachiopods. Faunal lists for the Wills Creek have been published by Swartz (1923) and by Alling and Briggs (1961).

Sedimentation

The interbedded claystone, calcareous shale, and limestone, and the flaser-bedded siltstone and sandstone indicate that the Wills Creek is a nearshore and onshore (epineritic and littoral) shallow marine deposit. The Wills Creek in the Millerstown area was deposited west of the Bloomsburg-Vernon delta which developed in eastern Pennsylvania, eastern Maryland, and southeastern New York during Niagaran and Cayugan time, and formed the southeastern margin of the Appalachian basin. During this time, argillaceous evaporates and red beds were being deposited farther north and west in New York and western Pennsylvania (Alling and Briggs, 1961).

An analysis of the sedimentary structures, algal mats, and petrology of the Wills Creek Formation at Mount Union, Pennsylvania (35 miles or 56 km west-southwest of the Millerstown quadrangle) by Hoffman (oral commun., 1969) indicates that the formation there is a tidal-flat deposit, having cyclicity which represents an alternation of subtidal, intertidal, and supratidal sediments. Hoffman suggests that the Wills Creek was deposited in an environment of low mechanical energy, highly saline water and in an arid climate. Gwinn and Bain (1964), in a study of the carbonates in the same section, concluded that the cyclicity was a result of a regular shoaling of the water with a concomitant increase in salinity. No indication of saline beds was observed in the Millerstown quadrangle.

These three studies show that the Wills Creek Formation in the Millerstown area was deposited in environments which were transitional between the highly saline, evaporite conditions which prevailed to the west and northwest and the deltaic conditions which existed to the east. These regional relationships imply that the Wills Creek in the Millerstown area is laterally equivalent to the Bloomsburg Formation farther east, as suggested by Swartz (1934).

Tonoloway Formation

Name and Extent

The Tonoloway Formation is an interval of distinctively laminated carbonates which overlies the Wills Creek Formation and underlies the nodular carbonates of the Keyser Formation. The Tonoloway was named by Ulrich (1911) for exposures on the east flank of Tonoloway Ridge in Morgan County, West Virginia. The formation in central Pennsylvania is part of the original Scalent Limestone of Rogers (1858).

The Tonoloway Formation is present in the Appalachian Valley and Ridge province in central and south-central Pennsylvania, Maryland, Virginia, and eastern West Virginia.

Character

The Tonoloway Formation consists primarily of laminated to thin-bedded limestone (Figure 17) and some thin beds of medium-gray calcareous shale (which typically weathers light olive gray). The laminated appearance on weathered surfaces results from the alternation of micrite or calcisiltite in argillaceous and silty layers. Occasional thin to medium beds of dense gray microcrystalline limestone are also present. Pellet texture, scattered ostracod shells, lenses of crystalline calcite and sedimentary boudinage structures were also observed.

Although dolomite and dolomitic limestone have been reported from this formation in central Pennsylvania (Swartz, 1955; Gwinn and Bain, 1964), no dolomite was found in the Tonoloway in the Millerstown quadrangle.

Outcrop Area and Thickness

A poorly developed karst topography occurs in terrain underlain by the Tonoloway and Keyser Formations. Local areas of interior drainage, generally from one to three acres in size, occasionally contain swamps and small ponds.

Like the Wills Creek Formation, the Tonoloway Formation underlies the broad valleys off the flanks of both Tuscarora and Shade Mountains. Outcrops are rare. The only Tonoloway exposure in the area in which both contacts are exposed occurs in the bed of Mahantango Creek at Mahantango, Pennsylvania, in the adjacent Millersburg quadrangle. This exposure is located along the Juniata-Snyder County line, between old U.S. Route 11 and the relocated Route 11. A measured section at this locality (Hoskins, in preparation) indicates that the Tonoloway Formation is only 110 feet (34 m) thick. However, the interval included in the Tonoloway probably does not cover all the strata which are mapped as Tonoloway Formation in the Millerstown quadrangle, because of lateral

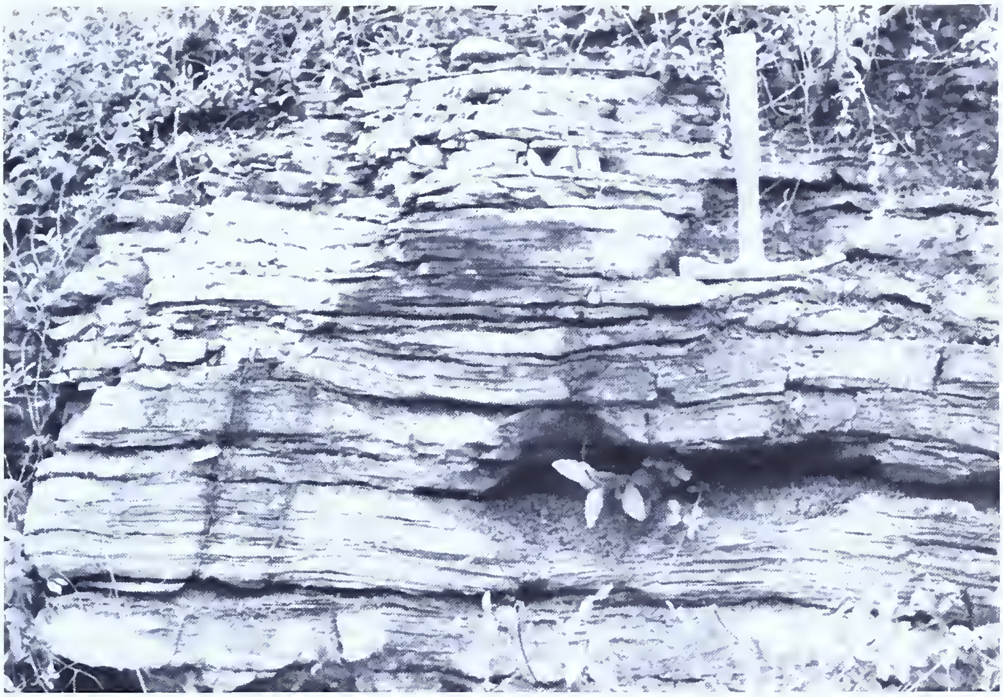

Figure 17. Tonoloway limestone exposure on the Barner farm in Pfoutz Valley, Liverpool Township, Perry County.

changes in lithology (eastward thinning of limestone beds) and the interbedded nature of the Tonoloway-Wills Creek contact. The upper 15 feet (4.6 m) of the Tonoloway Formation is exposed in the Juniata Limestone Company quarry on Lost Creek Ridge (Figures 18, 19, and 101), and is described in Appendix I, locality 3. See Table 12 for the thickness of the Tonoloway Formation across central Pennsylvania.

The Tonoloway is estimated to be from 500 to 600 feet (152 to 183 m) thick in the Millerstown quadrangle, based on topographic expression and outcrop pattern.

The Tonoloway Formation thins quite gradually toward the east across much of central Pennsylvania. However, in the Susquehanna River Valley (Table 12) it thins quite rapidly and is absent entirely on Blue Mountain near Suedberg. This reported thinning is due partly to nondeposition (Wood and others, 1969) and partly to a primary lateral change from a limestone (Tonoloway) to a shale (Wills Creek) facies.

Formation Boundaries

Both the upper and lower contacts of the Tonoloway are apparently conformable in the Millerstown quadrangle. The contact with the overlying Keyser limestone can be seen in the limestone quarry on Lost Creek Ridge (Figure 19). The contact there is chosen at a distinct, persistent

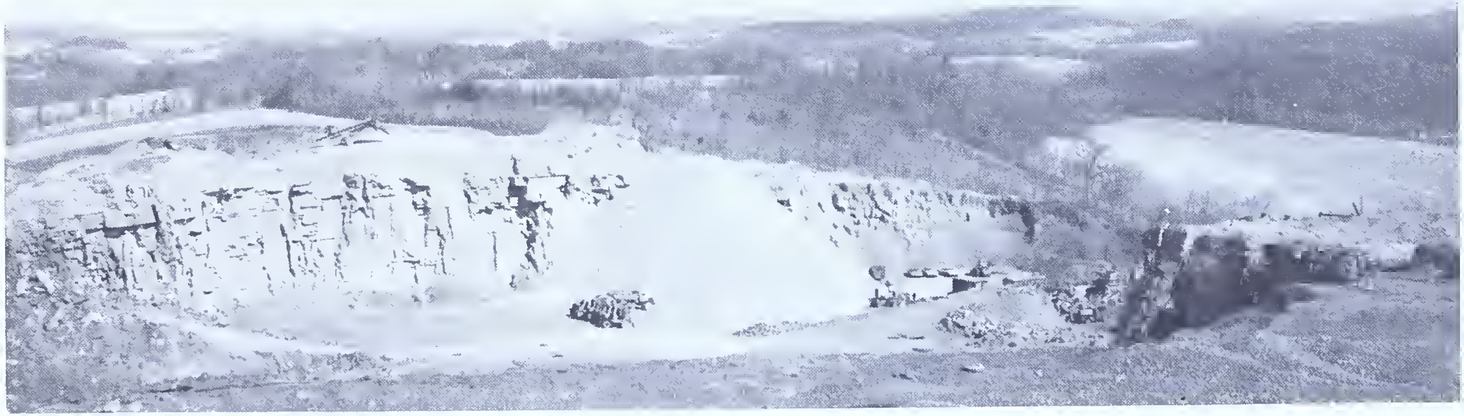

Figure 18. Tonoloway and Keyser Formations exposed in Cocolamus anticline, Juniata Limestone Company quarry on Lost Creek Ridge, Fayette Township, Juniata County. The structure appears superficially to be a very open, concentric anticline but is actually the interlimb of a conjugate fold. Site of locality 3 (Appendix I). View looking east.

Table 12. *Thickness Values for the Tonoloway Formation in Central Pennsylvania*

Locality	Quadrangle*	County	Thickness (feet)	(meters)	Source
Mount Union	Mount Union 7½′	Mifflin	820	250	Swartz, 1934
Strodes Mills	Lewistown	Mifflin	790	241	Swartz, 1934
none specified	Mifflintown	Juniata, Mifflin	550–600	168–183	Conlin and Hoskins, 1962
Mahantango, Pa.	Millersburg	Juniata, Snyder	110	34	Hoskins, in prep.
central part	Loysville	Perry	650	198	Miller, 1961
Susquehanna Gap	Harrisburg	Perry	41	12.5	Dyson, 1967
			(partial thickness)		
northern part	New Bloomfield	Perry	400–500	122–152	Dyson, 1967
Blue Mountain	Lykens	Lebanon	0	0	Wood and others, 1969

* Refers to 15-minute quadrangle unless otherwise stated.

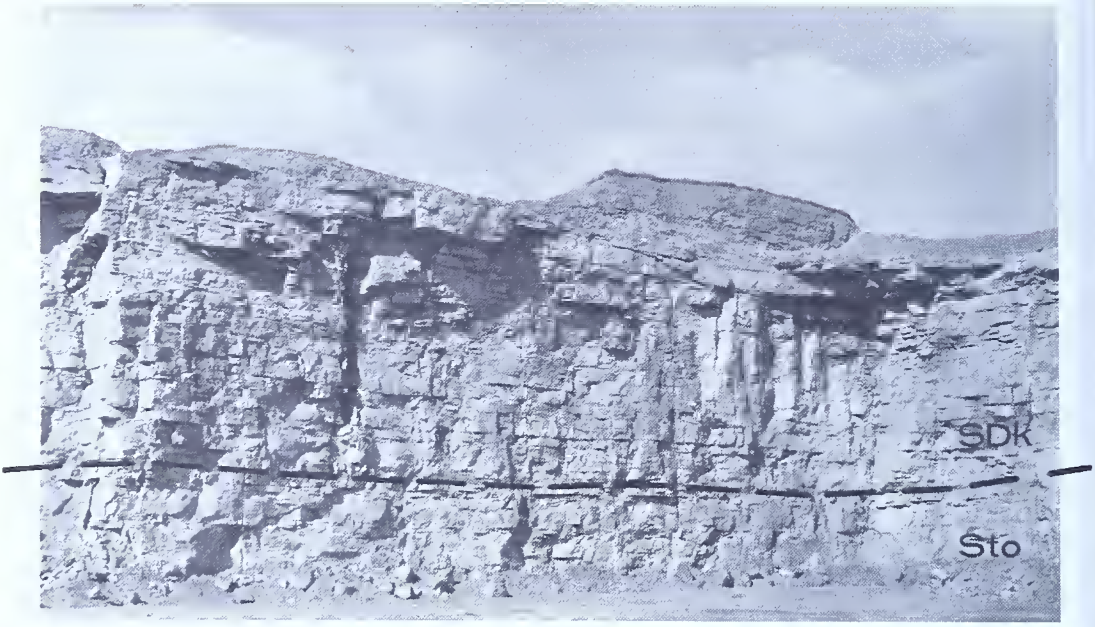

Figure 19. North wall of quarry pictured in Figure 18. Top of the Tonoloway Formation is marked by the dashed line. Height of cliff is 78 feet.

bedding plane which separates predominantly laminated limestone below from thicker bedded, locally nodular, cobbly-weathering limestone above. The Keyser limestone is more fossiliferous than the Tonoloway, and according to Ulrich (1911) there is a marked faunal break at the contact.

Age

The Tonoloway Formation is Upper Silurian (Cayugan) in age (Swartz and others, 1942). Wood and others (1969) place the formation in the middle Late to latest Late Silurian and Berry and Boucot (1970) correlate it with the Pridoli Series.

Sedimentation

The presence of a varied brachiopod and mollusc fauna and algal structures in the Tonoloway suggests deposition under conditions of normal salinity, whereas the occurrence of desiccation cracks and occasional anhydrite laminae (reported by Hoskins from the Mahantango Creek section) suggests periodic conditions of hypersalinity. LaPorte (1969) suggested that much of the Tonoloway Formation was deposited in an intertidal environment.

The interfingering with the underlying Wills Creek Formation and the replacement of the lower Tonoloway beds by shales of Wills Creek lithology to the east and south (Dyson, 1963; Miller, 1961; Hoskins, in preparation) indicate that the epeiric sea which covered this portion of the Appalachian basin was subject to repeated fluctuations in type of sediment and rate of deposition. The change in dominant sediment type from carbonate to clay and silt toward the east and south implies that land areas at the edge of the basin lay in those directions.

Swartz (1939, p. 35) postulated that a low-lying landmass existed from southeastern Perry to Schuylkill Counties during late Silurian and early Devonian time which he called the Auburn Promontory. This landmass resulted from intermittent epeirogenic uplift which was responsible for thinning and nondeposition in the Tonoloway, Keyser, and Old Port Formations, and an increase in sand and pebble content in these units in this area. Wood and others (1969) suggest that the Auburn Promontory underwent rejuvenation during the deposition of the Selinsgrove (Onondaga) limestone and became a major source area during the deposition of the Montebello Member of the Mahantango Formation.

SILURIAN AND DEVONIAN SYSTEMS, UNDIVIDED

Carbonate sedimentation in central Pennsylvania, represented by the Keyser Formation, appears to have been continuous from late Silurian into early Devonian time, because both Silurian and Devonian fossils occur within it (Berdan, 1964; Bowen, 1967).

Keyser Formation

Name and Extent

The name Keyser Formation was originally used by Ulrich (1911) for a distinctive limestone unit which was part of Rogers' Pre-Meridian Limestone, and was named for exposures near the village of Keyser in Mineral County, West Virginia. The Keyser Formation is recognized throughout the central Appalachian basin from east-central Pennsylvania to western Virginia and northern West Virginia.

Character

The Keyser Formation is predominantly a medium-gray, fossiliferous, lumpy or "pseudo-nodular" limestone which is very cobbly when weathered. The color is consistently gray, ranging from dark to medium light gray. The limestones are predominantly micritic calcisiltites, bioclastic calcarenites and skeletal micrites. The upper part of the formation contains laminated to thin-bedded limestone that is very similar to the underlying Tonoloway beds, and dark-gray chert nodules are common in the upper few feet.

The Keyser is thin to very thick bedded, and often appears massive with no visible bedding planes. Stylolites parallel to bedding are common. The thin- to medium-bedded units are generally nonfossiliferous calcisiltite, and subordinately bioclastic calcarenite, interbedded with calcareous shale. The calcisiltite and calcarenite beds are usually fragmented and separated into roughly equidimensional cobbles. The discontinuity surfaces (fractures?) in these beds are inclined from 45 to 60 degrees to bedding, and generally filled with calcareous shale. This "brecciation" of the coarser grained, more brittle beds and intrusion by the more ductile shale gives the Keyser its distinctive cobbly or nodular appearance on weathering. Whether this fragmentation developed before or during folding is not known. Knowles (1966) attributes this fragmentation to either downslope movement of semiconsolidated beds or to compaction. The cleavage and fragmentation in the Keyser are particularly well displayed in a sinkhole on the Scales farm in Pfoutz Valley (Figures 20 and 85).

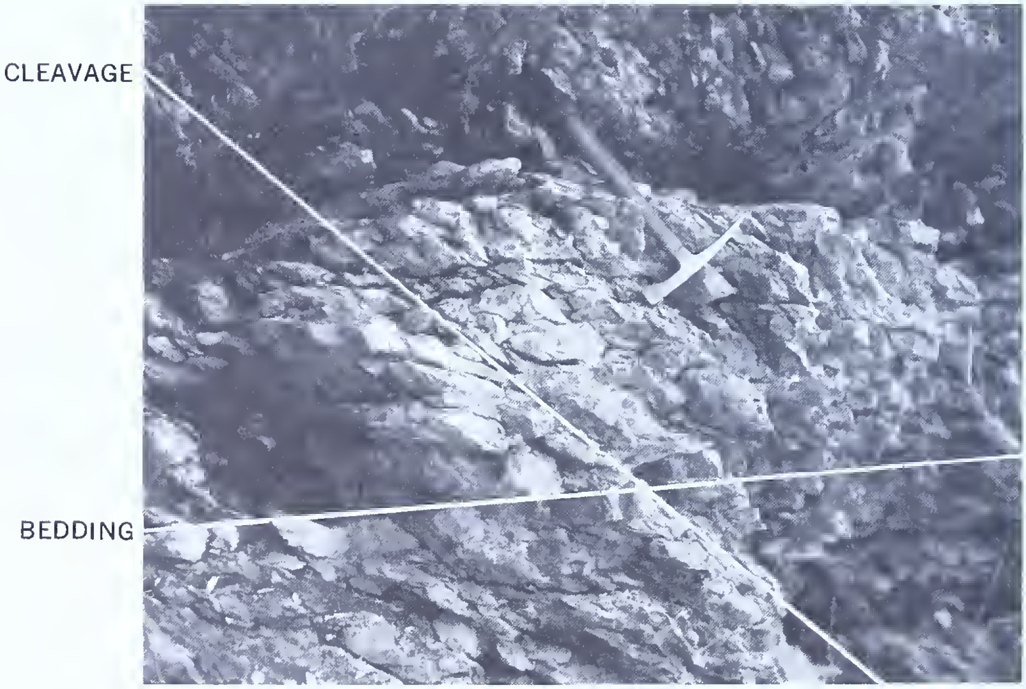

Figure 20. Keyser Formation outcrop in an abandoned limestone quarry on the Scales farm in Pfoutz Valley, Liverpool Township, Perry County. Note the development of cleavage planes and the alignment of angular limestone fragments. Average attitude of bedding here is N66W, 22SW; average attitude of cleavage is N68E, 54NW.

The fossils in the Keyser are generally disarticulated and broken fragments of brachiopods, crinoids, bryozoans, molluscs, and ostracods. Whole specimens are also common and the formation provides several good fossil-collecting localities. One such locality is the area on the west side of Pa. Route 275, 1 1/2 miles (2.5 km) north of Thompsontown (Plate 3). The top and southeast slopes of this hill, which forms the south side of Kurtz Valley, are covered with fossiliferous limestone float.

Insoluble residues of the Keyser limestone consist entirely of light- to very light gray clay and very fine quartz silt. The insoluble content ranges from 8.8 to 20.8 percent. A chemical analysis of a representative sample of the Tonoloway and Keyser beds exposed in the Juniata Limestone Company quarry on Lost Creek Ridge is presented in Appendix II, and the measured section is described in Appendix I, locality 3 (see Figures 18 and 19). O'Neill (1964) has also published a chemical analysis of the limestone from this quarry. At this locality are some rather extensive but discontinuous veins of white crystalline calcite, occasionally containing minor amounts of white and purple fluorite.

Locally, extensive travertine deposits occur in small caves and sinkholes (e.g., in the quarries on Lime Ridge north of Mount Pleasant Mills, Figure 21).

Outcrop Area and Thickness

The areas underlain by the Keyser Formation are usually situated on the scarp slopes of monoclinal Lower Devonian ridges in the northern part of the quadrangle (e.g., Firestone and Flint Ridges), and at the base of the monoclinal Lower and Middle Devonian ridges in the southern portion (e.g., Wildcat and Turkey Ridges). Locally, the Keyser is exposed on the crests of some of the smaller anticlinal and synclinal ridges (e.g., Lime and Lost Creek Ridges). A rather distinctive terrace is developed in the middle of the Keyser at some places. This terrace separates the steep slopes of the lower part of the formation from the gentler slopes underlain by the upper portion (Firestone and Flint Ridges). Throughout the quadrangle, the Keyser outcrop belt is dotted with small abandoned quarries from which lower Keyser limestone has been removed in the past to supply local kilns producing agricultural lime.

No complete exposure of the Keyser Formation exists in the quadrangle. The most complete section occurs in the Juniata Limestone Company quarry on Lost Creek Ridge (Appendix I, locality 3). The thickness of the Keyser ranges from 150 to 200 feet (48 to 61 m) in the Millerstown quadrangle, comparable to the thicknesses measured in surrounding quadrangles (Table 13).

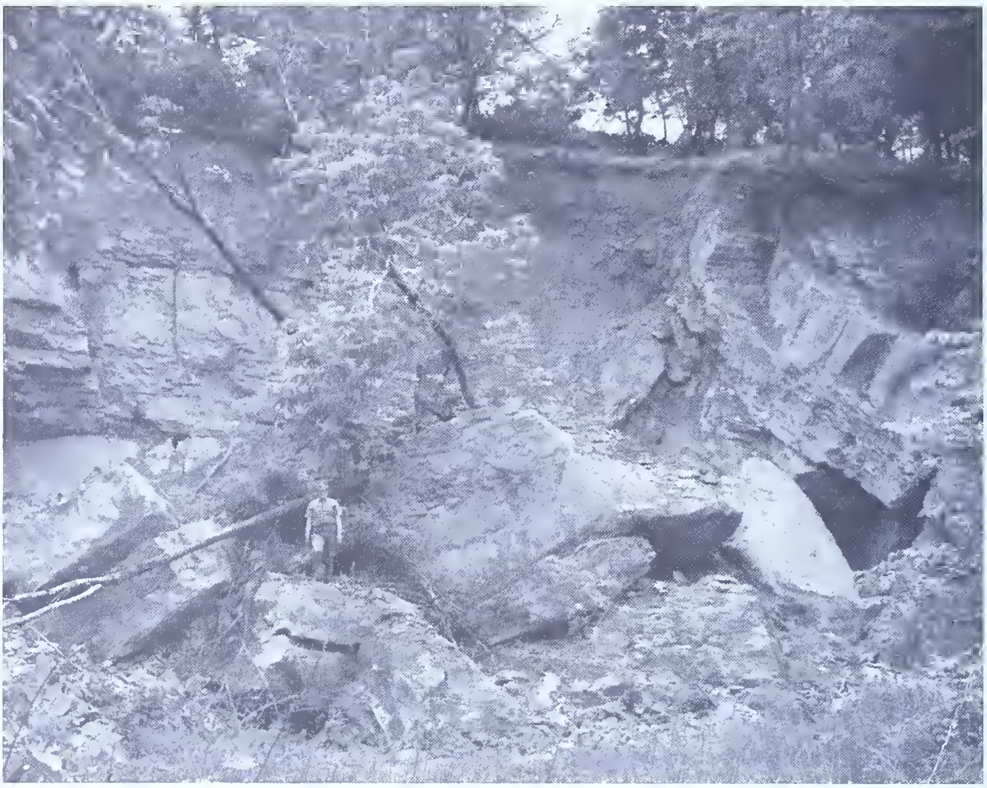

Figure 21. Keyser limestone outcrop in quarry on Limestone Ridge north of Mount Pleasant Mills in Perry Township, Snyder County. A large rockfall has occurred here due to oversteepening of the slope during quarrying operations and cavern collapse. Entrance to small cave is behind large block at right. This quarry is believed to have been originally opened at the site of an old sinkhole. Extensive travertine deposits and speleothems occur on the quarry walls.

Formation Boundaries

The lower contact of the Keyser is sharp and conformable, as exposed in the quarry wall of the Juniata Limestone Company on Lost Creek Ridge (Figure 19). The fossiliferous, nodular beds of the Keyser contrast sharply with the underlying poorly fossiliferous, laminated limestone of the Tonoloway.

The upper contact with the Old Port Formation is less distinctive, and is rarely exposed in the Millerstown quadrangle. The upper Keyser limestones grade upward into shale and into limestone having occasional dark-gray chert nodules. This grades into a mixed limestone, cherty limestone, and bedded chert sequence, overlain by the predominantly chert layers characteristic of the Old Port Formation.

Table 13. *Thickness Values for the Keyser Formation in the Vicinity of the Millerstown Quadrangle*

Locality	Quadrangle**	County	Thickness (feet)	Thickness (meters)	Source
Clarks Mill	New Bloomfield	Perry	150	46	Dyson, 1963
Mexico, Pa.	Mifflintown	Juniata	180	55	Conlin and Hoskins, 1962
Selinsgrove Junction	Sunbury 7½′	Snyder	202	62	Miller, 1934
Dalmatia	Millersburg	Northumberland	158	48	Hoskins, in prep.
Hooflander Mountain*	Lykens	Northumberland	75	23	Wood and others, 1969
Pine Grove	Loysville	Perry	165–175	50–53	Miller, 1961
northern half	New Bloomfield	Perry	140–160	43–49	Dyson, 1963

* Thickness includes Coeymans and New Scotland Members of the Helderberg Formation, which are not differentiated from the Keyser in this area.

** Refers to 15-minute quadrangle unless otherwise stated.

To the west in the Mifflintown quadrangle, the top of the Keyser is marked by a distinct chert bed (Conlin and Hoskins, 1962). To the east, Wood and others (1969) include the Helderberg with the Keyser because of poor exposures and because of the lithologic similarity between the Coeymans and New Scotland Members and the underlying limestone units.

Age

The Keyser Formation was originally described as the oldest Devonian formation in the central Appalachians (Ulrich, 1911). Since that time, the age of the Keyser has been controversial, because its fauna has both Upper Silurian and Lower Devonian aspects. Reeside (1917) assigned the Keyser to the Devonian, Swartz and Swartz (1941) tentatively concluded that the Keyser was Silurian, and the Geological Society of America Correlation Charts (Swartz and others, 1942) list it as Silurian and questionably Devonian. Boucot (1957) pointed out the Keyser could be considered as either Lower Devonian or Upper Silurian, depending on whether brachiopods or graptolites are used for correlation with the type areas in Europe. Bowen (1967) recognized two brachiopod faunal zones, an upper *Meristella praenuntia* Zone and a lower *Eccentricosta jerseyensis* Zone. Bowen concluded that (p. 17) "The evidence is not strong in any direction, but placing the boundary within the Keyser Limestone, between the two faunal zones, best fits present data."

Recent correlation charts by Berry and Boucot (1970), Oliver and others (1969), and Berdan and others (1969) show the Keyser Formation as both Silurian and Devonian in age. The Silurian part of the Keyser correlates with the upper part of the Pridoli Series, and the Devonian interval is assigned to the Helderberg (Gedinnian) Stage.

Sedimentation

The richer, more diverse fauna, the small amount of clay, and the absence of evaporites in the Keyser as compared to the Tonoloway Formation indicate that conditions had changed. The broad, shallow epeiric sea which had occupied most of the Appalachian basin since the submergence of the Bloomsburg delta in Middle Silurian time had become slightly deeper, sources of terrigenous sediment were more remote, and conditions of normal salinity and good circulation prevailed.

LaPorte (1969) indicates that tidal-flat and shallow subtidal conditions prevailed on the central Appalachian shelf during the deposition of the Keyser. However, unquestioned tidal-flat sediments have not been recognized in the Keyser in the Millerstown quadrangle, although they may be represented by the laminated beds in the upper portion.

Head (1969) described the variations in marine sedimentary environments which existed during the deposition of the Keyser Formation. His reconstruction of the paleogeography of the Appalachian basin, based on the distribution of lithofacies and biofacies in the Keyser, indicates that this area was near the bathymetric axis of a basin which was open to the southwest and restricted or closed on the other three sides.

DEVONIAN SYSTEM

The Devonian section in central Pennsylvania is thick and well exposed. These formations were first studied and correlated with the Devonian of New York State by Rogers (1858). Oliver and others (1969, 1971) traced the thickness, lithofacies, and subsurface correlations of the Devonian across the Appalachian basin, and Jones and Cate (1957) discussed the regional stratigraphic relationships of the Devonian in Pennsylvania.

In the Millerstown quadrangle, the Lower Devonian is represented by limestone, calcareous shale, and chert beds in the Keyser and Old Port Formations, and by the Needmore Shale Member of the Onondaga Formation. Except for the thin Selinsgrove Limestone Member of the Onondaga at the base, the Middle Devonian is entirely clastic, as are all of the succeeding formations in this area. Middle Devonian formations above the Onondaga include the Marcellus black shale and the Mahantango Formation, a series of upward-coarsening cycles of shale, silty claystone, siltstone, and (locally conglomeratic) sandstone. The Upper Devonian strata consist of thick, interbedded sandstone, siltstone, and shale of the marine Trimmers Rock and Harrell Formations and the largely nonmarine, upward-fining cyclic Catskill Formation (Plate 4).

The Lower and Middle Devonian strata represent a pre-orogenic phase of sedimentation in the Appalachian geosyncline, and the thicker Upper Devonian formations comprise the Late Paleozoic flysch (Trimmers Rock Formation) and molasse (Catskill Formation) sediments.

Old Port Formation

Name and Extent

The term "Old Port Formation" was proposed by Conlin and Hoskins (1962) for the interval of limestone, shale, chert, and sandstone overlying the Keyser Formation and underlying the Needmore Shale Member of the Onondaga Formation. The many named rock units which occupy this stratigraphic interval in central New York and western Maryland are not easily mapped in central Pennsylvania because they are thin, locally absent, or poorly exposed. The Old Port Formation is a local, rather than a regional, term and has been used only from the lower

Juniata Valley to the Everett quadrangle in Bedford County. Willard and others (1939) discussed the regional relationships of the Old Port rocks to the Helderberg and Oriskany groups elsewhere, and Head (1974) discussed the correlation and paleogeography of the Helderberg Group in the central Appalachians.

Character

Although the Old Port is lithologically quite diverse, the rock type which is most characteristic is a whitish-weathering dark-gray to black chert. The main body of chert in the Old Port is underlain by calcareous shales and thin limestone beds which are equivalent to the Helderberg Formation, and is locally overlain by a thin, porous sandstone, the Ridgeley Member.

The limestone is medium gray to blue gray, thin, generally microcrystalline, slightly siliceous, fossiliferous, locally pyritic, and contains cryptocrystalline chert. The shale is usually gray brown, silty to locally very sandy, and poorly fissile (Figure 22).

The chert is dark gray to black and becomes light gray to white or yellow brown on weathering. It is in the form of cryptocrystalline silica,

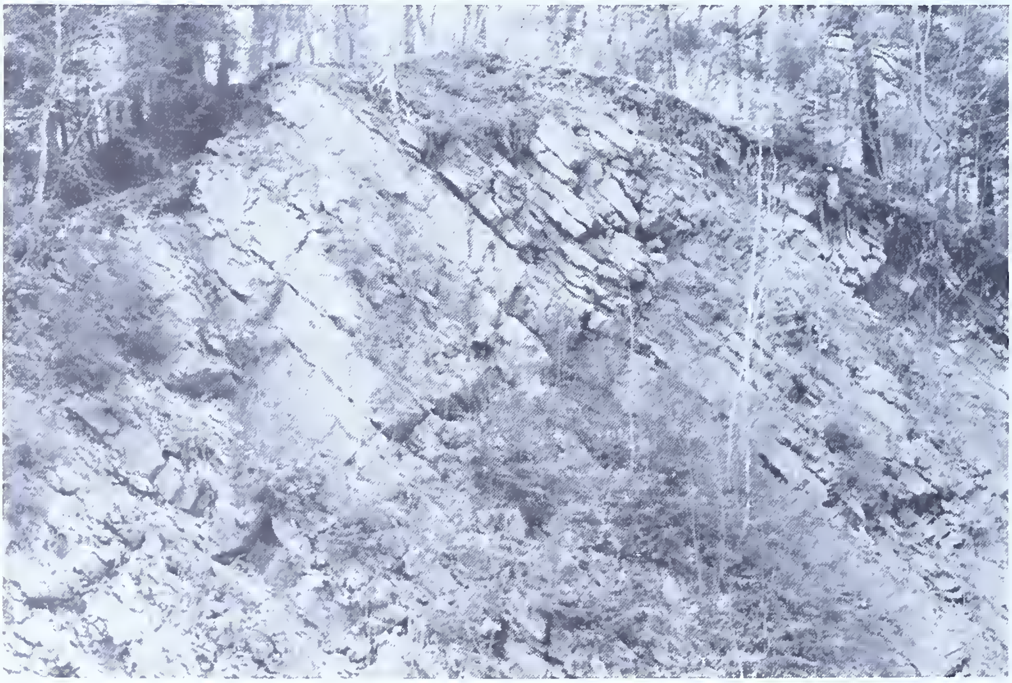

Figure 22. Old Port Formation exposure on the east end of Firestone Ridge on Maple Street, Beaver Springs, Snyder County. View looking west. Bedding attitude is N71E, 43NW.

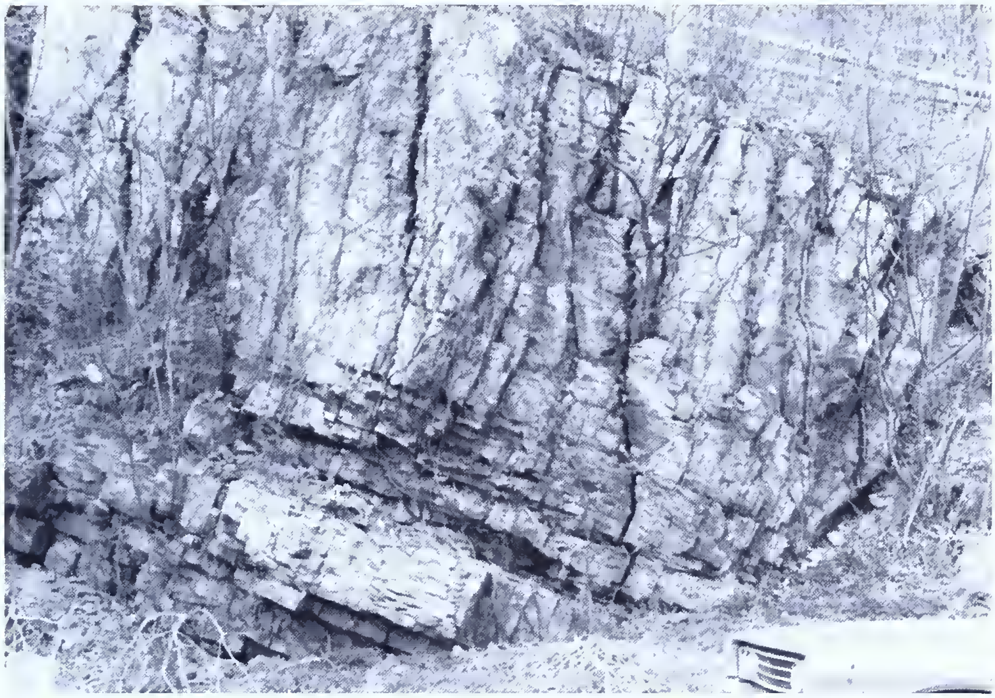

Figure 23. Outcrop of Ridgeley sandstone on northbound lane of U.S. Route 22-322 at Midway, Pennsylvania, 9 miles south of Millerstown (Duncannon 7½-minute quadrangle).

often displaying a distinctive radial structure, and is commonly mixed with microcrystalline calcite and quartz silt. The chert is nodular, thin bedded or massive, slightly calcareous, and possesses a high density of fractures which are often filled with thin, white calcite veins. The great fracture density imparts a blocky character in weathered outcrops, and these sharp, quasi-rectangular chert fragments form a scree deposit which usually conceals the underlying strata for considerable distances downslope. The chert is locally quite fossiliferous, with large spiriferoid brachiopods and gastropods occurring in abundance. Radiolarians and foraminifera are present, and authigenic quartz crystals occur as vug fillings.

The Ridgeley Member is a white, light-gray or buff, predominantly medium grained quartz arenite, very fine to very coarse grained, or conglomeratic, medium- to thick-bedded, slightly siliceous, slightly limonitic, fossiliferous, and fairly to extremely porous (Figure 23). It consists of 95 to 98 percent well-rounded quartz grains; detrital chert, composite quartz grains, and quartz silt are present in small amounts. Well-rounded white quartz pebbles up to a half inch (1.2 cm) long occur only rarely. The framework is partially cemented with silica, and a microcrystalline calcite matrix is sometimes present. Porosity of the Ridgeley Member usually ranges from 10 to 20 percent, but in some instances it is somewhat greater. Because of the arrangement of the silica cement, the permeability of the rock is excellent, imparting to the Ridgeley all of the characteristics of a good reservoir rock capable of storing and transmitting significant volumes of fluid. The petrology, petrography, and origin of the Ridgeley have been described by Stow (1938) and Seilacher (1968).

Good fossil-collecting localities are often found in the Old Port Formation. Two of these are the Beaver Springs outcrop mentioned above (Figure 22) and the area on the east side of Pa. Route 275 one mile (1.7 km) south of East Salem in Juniata County. The fields on the east side of this hill contain fragments of Old Port limestone and chert; silicified fossils weather out in the float.

Outcrop Area and Thickness

The chert and cherty limestone beds of the Old Port Formation are fairly resistant to erosion, and in the northern part of the quadrangle underlie the crests of ridges (e.g., Firestone and Flint Ridges). In the southern part of the quadrangle, the Old Port occurs near the foot of the scarp slopes of the Middle Devonian ridges (e.g., Wildcat and Raccoon Ridges).

Good exposures of the Old Port Formation can be seen on Maple Street in Beaver Springs, on Lime Ridge 0.2 mile (0.3 km) north of Mount Pleasant Mills, and on the west side of Cocolamus Creek at Cocolamus. Outcrops of the Ridgeley Member are rare in the quadrangle, but can be seen at the Lime Ridge exposure cited above, and on the extension of Flint Ridge a half mile (0.8 km) east of Richfield.

The Old Port Formation is 50 to 100 feet (15 to 30 km) thick. Willard and others (1939, Figure 29) presented a stratigraphic cross section showing the thickness variations in the Ridgeley and Shriver Formations at 17 localities in central and eastern Pennsylvania.

Formation Boundaries

The lower contact, generally covered by chert float, appears to be conformable and gradational.

Wood and others (1969) have mapped an unconformity at the base of the Ridgeley Member, where the pre-Ridgeley strata have been removed down to the Bloomsburg Formation. The Ridgeley is discontinuous in the Millerstown quadrangle, but the unconformity is not exposed here.

The upper contact consists of a rather abrupt change from chert or sandstone to the overlying Onondaga (Needmore) shales. A post-Ridgeley disconformity has been postulated (Willard and others, 1939; Oliver and others, 1969) for the central Pennsylvania area.

Age

The Old Port Formation is Lower Devonian in age, and is correlated with the Helderberg and Deerpark stages of the Ulsterian Series of the North American Standard Section (Oliver and others, 1969). Faunal lists for the Old Port Formation and equivalent strata in central Pennsylvania have been published by Reeside (1917), Willard (1932), Willard and others (1939), and Swain (1958).

The Ridgeley Member correlates with the Oriskany Sandstone of New York State. The chert interval of the Old Port has traditionally been considered the equivalent of the Shriver chert because of the similarity of its fossils with those of the Shriver in Maryland (Conlin and Hoskins, 1962). However, its lithologic character is more similar to that of the Corriganville chert of western Maryland and Bedford County, Pennsylvania.

Sedimentation

The Old Port Formation includes a variety of rock types which were deposited in a number of different local environments; however, they all bear the imprint of shallow to marginal marine sedimentation. The limestones are largely recrystallized, so that their original texture has been destroyed and primary structures obscured. The diverse faunal assemblage (Reeside, 1917) in the limestones of the Old Port (Helderberg) indicates that the temperature was fairly warm, the salinity was normal, turbidity was low, and circulation unrestricted. The chert in the Old Port may be either a product of direct precipitation from sea water or an early replacement of microcrystalline limestone. Although some of the chert has replaced earlier carbonate, most of it is in a cryptocrystalline form, and probably resulted from the precipitation of colloidal silica.

The Ridgeley Member is not sufficiently exposed in the quadrangle to permit detailed sedimentological analysis, but its petrographic character, marine fauna, and excellent porosity suggest it is a high-energy shoreline deposit of sands which were derived from older sedimentary rocks. Seilacher (1969) concludes that the Ridgeley is a beach deposit, and Stow (1938) suggested that the Oriskany (Ridgeley) is a transgressive deposit throughout central Pennsylvania. Krynine (1941) noted the presence of quartzite, chert, and sedimentary rock fragments in the Oriskany and concluded that it is a second-cycle sandstone, i.e., one in which the sands were derived from older sedimentary rocks.

Onondaga Formation

Name and Extent

The term Onondaga Formation has been in general use in the central Appalachians since it was first applied in central New York by Hall (1839). The rocks included in the Onondaga in central Pennsylvania were originally part of Rogers' (1858) Post-Meridian Limestone. Claypole (1891), Kindle (1912) and others verified the correlation of these beds in central Pennsylvania with the Onondaga Formation in the type area in Onondaga County, New York. The current usage of the Onondaga was established by Willard and others (1939), who adopted the name Selinsgrove Limestone (White, 1883) for the upper member, and proposed the new name Needmore Shale for the lower member. For a more complete description of the usage and terminology of the Onondaga see Kindle (1912) and Willard and others (1939). The Selinsgrove and the Needmore Members of the Onondaga can be recognized in the measured section at Wardville (Appendix I, locality 3), but are not mapped separately in the quadrangle.

The Onondaga Formation is a mappable unit with characteristic faunas which is recognized from southern Ontario to western Virginia and West Virginia. It is present in Pennsylvania wherever Devonian rocks are preserved, except from southeastern Perry to Schuylkill Counties, the area of the postulated Auburn Promontory (Swartz, 1939).

Character

The Needmore Member (lower shale) of the Onondaga Formation is a medium-gray to medium-light-gray, fissile, generally calcareous shale which becomes light olive gray toward the base. Thin, fossiliferous limestone lenses occur in the upper half of the member, which is gradational with the overlying Selinsgrove Member.

The Selinsgrove Member (upper limestone) of the Onondaga Formation is a dark- to medium-gray, dense, microcrystalline to very finely crystalline, fossiliferous, argillaceous, locally carbonaceous limestone, which is thin, medium, and thick bedded. Thin sections of the Selinsgrove Member from Wardville show that the limestone is predominantly an argillaceous biomicrite, with up to 90 percent broken and comminuted skeletal material, principally ostracods and small brachiopod shells. Insoluble residues comprise as much as 34 percent (average 15 percent) of the limestones, and consist of slightly silty, brownish-black carbonaceous clay, with traces of pyrite and siliceous or chitinous shell material. Swain (1958) extracted light-brown, brownish-yellow, and greenish-brown wax, grease, and oil from samples of the Onondaga limestones at Mount Union, Pennsylvania. This suggests that the Onondaga is a potential petroleum source rock, at least in the Mount Union area. A comparison of Swain's description of the Onondaga at Mount Union with the Wardville section in the Millerstown quadrangle indicates that it is similar in both localities.

The Tioga bentonite (metabentonite, K-bentonite, or tuff bed) is a thin zone of interbedded micaceous shale, very fine grained sandstone, and limestone at the top of the Onondaga Formation (Fettke, 1952; Dennison and Textoris, 1968). This bentonite bed is a widespread deposit of crystal tuff, tuffaceous siltstone, and bentonitic shale which was deposited over the entire central Appalachian basin as ash falls associated with volcanic activity in west-central Virginia (Dennison, 1969). Units 20, 21, and 22 in the Wardville Devonian section (Appendix I, locality 3) represent the Tioga bentonite.

Lapham (unpublished manuscript) suggested that the term "K-bentonite" is preferable to "metabentonite" since there is little evidence of metamorphism. K-bentonite is a predominantly illitic clay containing randomly interstratified montmorillonite in approximately a 3:1 ratio of illite to montmorillonite, and containing textural and mineralogic characteristics retained from a volcanic ash or tuff, such as glass shards, high-temperature feldspars, and clay remnants of altered phenocrysts.

Outcrop Area and Thickness

Outcrops of the Onondaga Formation are rare in the Millerstown quadrangle. By far the most complete exposure of the formation is on the east side of the valley of Cocolamus Creek north of Wardville, site of the Wardville Devonian section (Appendix I, locality 3) (Figure 24). Partial exposures of the Onondaga Formation may be seen on the west side of Cocolamus Creek at Cocolamus (Needmore Member), in the south bank of Cocolamus Creek, 1.9 miles east of Millerstown, in the bed of Raccoon Creek a half mile west of the Juniata River, and on the west side of Pa. Route 275, 1.4 miles north of Thompsontown (Selinsgrove Member). The Onondaga Formation underlies the dip slopes of the Old Port ridges in the northern part of the quadrangle, and occurs near the base of the scarp slopes of the prominent Middle Devonian ridges in the southern portion (e.g., Raccoon and Wildcat Ridges).

The Onondaga is 167 feet (51 m) thick in the Wardville Devonian section, which includes 68 feet (21 m) of Needmore shale and 99 feet (30 m) of the Selinsgrove Member. Onondaga thicknesses in the surrounding quadrangles (Table 14) indicate a general southward and eastward thinning of the formation. Wood and others (1969) suggested that the wedge-shaped cross section of the Onondaga is a result of a very gentle northward tilting and slow subsidence of central Pennsylvania during Devonian time.

Dennison and Textoris (1968) measured a section through the Tioga bentonite in the Millerstown quadrangle, and recorded a thickness of 5.6 feet (1.7 m), which included 4.3 feet (1.3 m) of limestone (77 percent) and 1.3 feet (0.4 m) of shale and siltstone (23 percent) in thin and very thin alternations.

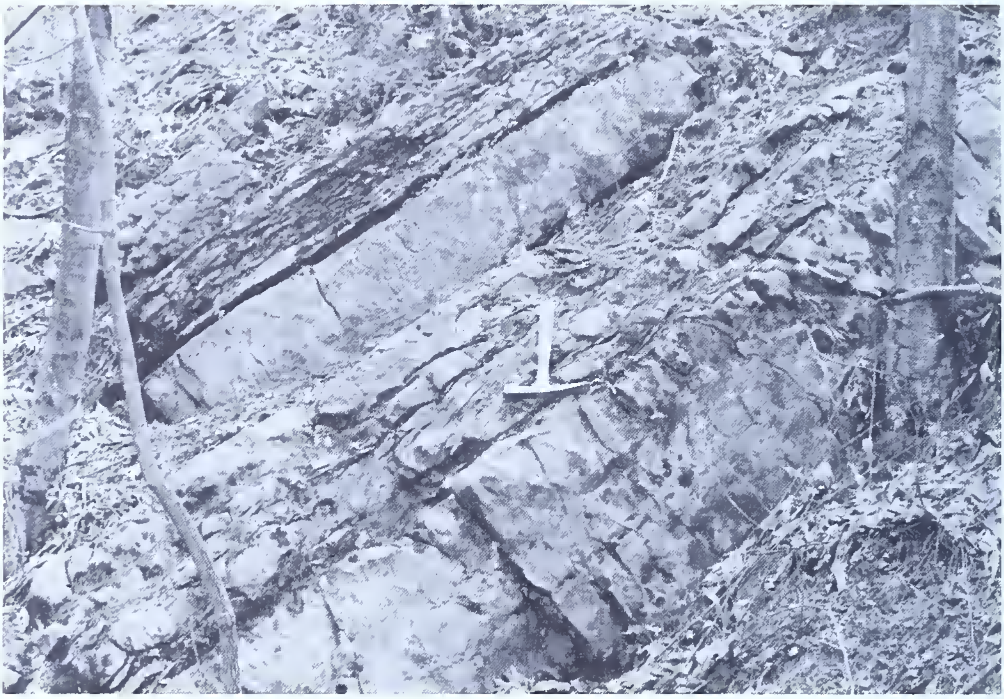

Figure 24. Exposure of the top of the Onondaga Formation on the east side of Cocolamus Creek, 0.3 mile north of Wardville in Greenwood Township, Perry County. The overlying Marcellus shale has been removed for use as surfacing material on unpaved roads in the area. Site of locality 3 (Appendix I).

Formation Boundaries

The contact of the Needmore and Selinsgrove Members of the Onondaga is entirely conformable and gradational, and is placed where the limestone beds become dominant over the shales. However, this contact is not mapped in the Millerstown quadrangle because both members are poorly exposed and the contact is seldom seen.

The contact of the Onondaga with the overlying Marcellus Formation is conformable and interbedded in the upper few feet of the Selinsgrove limestone. This contact is well exposed in the Wardville section (Figure 24).

Age

The age of the Onondaga Formation in central Pennsylvania and its correlation with the type section in central New York has been the subject of considerable study (Kindle, 1912; Willard, 1932; Willard and others, 1939; Swartz and Swain, 1941; Cooper and others, 1942; and

Table 14. *Thickness Values for the Onondaga Formation in Millerstown and Adjacent Quadrangles*

Locality	Quadrangle*	County	Thickness			Source
			Needmore Member	Selinsgrove Member	Total Onondaga	
Dalmatia	Millersburg	Northumberland	124′ (38 m)	59′ (18 m)	183′ (56 m)	D. M. Hoskins, in prep.
Wardville	Millerstown 7½′	Perry	68′ (21 m)	99′ (30 m)**	168′ (51 m)	Appendix I, this report
Milltown	Loysville	Perry			65′ (20 m)	Miller, 1961
Ickesburg	Loysville	Perry	45′ (14 m)	65′ (20 m)	110′ (34 m)	Miller, 1961
Old Port	Mifflintown	Juniata	100′ (30 m)	66′ (20 m)	166′ (51 m)	Conlin and Hoskins, 1962
New Bloomfield	New Bloomfield	Perry			135′ (41 m)	Dyson, 1963
Selinsgrove Junction	Sunbury 7½′	Northumberland	140′ (43 m)	56′ (17 m)	196′ (60 m)	Inners, in prep.

* Refers to 15-minute quadrangle unless otherwise stated.

** Includes Tioga beds, 4.5 feet (1.3 m) thick.

Oliver, 1954). Oliver and others (1969) show the Onondaga Formation as Lower and Middle Devonian in age, the boundary being placed at the contact of the Needmore and Selinsgrove Members. Both members are included in the Onesquethaw Stage of the Ulsterian Series of the North American Standard Section.

The Tioga bentonite is considered to be an essentially synchronous deposit from New York to eastern Ohio, Virginia, West Virginia, and eastern Tennessee. As such, it forms a time surface which is utilized to verify and refine many of the Devonian stratigraphic correlations which were originally established by other means.

Sedimentation

The highly fossiliferous, argillaceous limestones in the Onondaga suggest that it was deposited in a shallow epeiric sea with some input of terrigenous material. The reefs characteristic of the formation in the central New York outcrop belt are not seen in the Millerstown quadrangle. The increase in pyrite and carbonaceous matter in the upper beds of the Selinsgrove limestone indicate that circulation became restricted and reducing conditions prevailed toward the end of Onondaga sedimentation.

The occurrence of the Tioga bentonite beds at the top of the Onondaga Formation indicates a relatively brief period of vulcanism which punctuates the stratigraphic column in the Appalachian basin. The volcanic activity responsible for this ash fall was coincident with a major change in sedimentation from carbonate to clastics, and both may be related effects of a single tectonic event. Marine carbonate sedimentation has not occurred in the Millerstown quadrangle since that time.

Marcellus Formation

Name and Extent

The name "Marcellus" was originally applied to a sequence of black fissile shale which overlies the Onondaga limestone in central New York (Hall, 1839). Equivalent strata in central Pennsylvania were included in the Cadent Lower Black Slates (Rogers, 1858). The Marcellus was expanded by Willard (1935a) to include not only the black shale above the Onondaga, which he designated the Shamokin Member, but also two overlying sandstone units (Turkey Ridge and Mexico sandstones) and a supposedly present upper black shale unit (Mahanoy Shale).

However, the Turkey Ridge and Mexico sandstones are now considered to be part of the overlying Mahantango Formation. Thus the Marcellus is herein restored to its original definition, being restricted to the black shales between the Onondaga Formation and the Turkey Ridge Member of the Mahantango Formation. The term Shamokin therefore becomes redundant and is dropped.

The Marcellus Formation retains its essential lithologic character throughout a continuous outcrop belt which extends from central New York across the northwest corner of New Jersey and Pennsylvania into Maryland, West Virginia, and Virginia. The Marcellus Formation and the overlying Mahantango Formation comprise the Hamilton Group (Willard and others, 1939).

Character

The Marcellus is a homogeneous, highly fissile shale, dark-gray to black and brownish-black, carbonaceous, rarely fossiliferous, noncalcareous, slightly silty, and locally pyritic. In weathered outcrops it is light to medium gray, sooty, papery, and commonly carries a light-brown to dark-yellowish-orange limonitic stain on fracture surfaces. Along the eastern edge of the quadrangle thin sandstone beds occur in the lower part, and in the northeast corner of the quadrangle a few feet of light-gray argillaceous limestone and calcareous shale appears near the middle of the formation. This limestone is probably the southwestern edge of the "Upper Selinsgrove Limestone" of White (1883).

A detailed description of the Marcellus in the Wardville Devonian section is presented in Appendix I, chemical analyses of the shale from Wardville and Donnally Mills are given in Appendix II, and a ceramic analysis of the shale from Wardville is given in Appendix III.

Outcrop Area and Thickness

In the southern part of the quadrangle, the Marcellus shale occurs near the base of the scarp slopes of the homoclinal ridge formed by the more resistant quartzitic sandstones of the Mahantango Formation (e.g., Turkey Ridge and Wildcat Ridge). In the northern portion, the Marcellus (together with the Onondaga Formation) underlies swales between the Old Port and Turkey Ridge ridges. The best exposures are at Wardville (Figure 25) and on the west side of the road leading south from Donnally Mills (Appendix I, locality 4).

The Marcellus Formation is 106 feet (32 m) thick at Wardville, a thickness consistent with thicknesses measured in surrounding quadrangles (Table 15).

Formation Boundaries

As mentioned above, the basal contact of the Marcellus Formation with the underlying Onondaga Formation is conformable and rather abrupt. The upper contact of the Marcellus with the Turkey Ridge

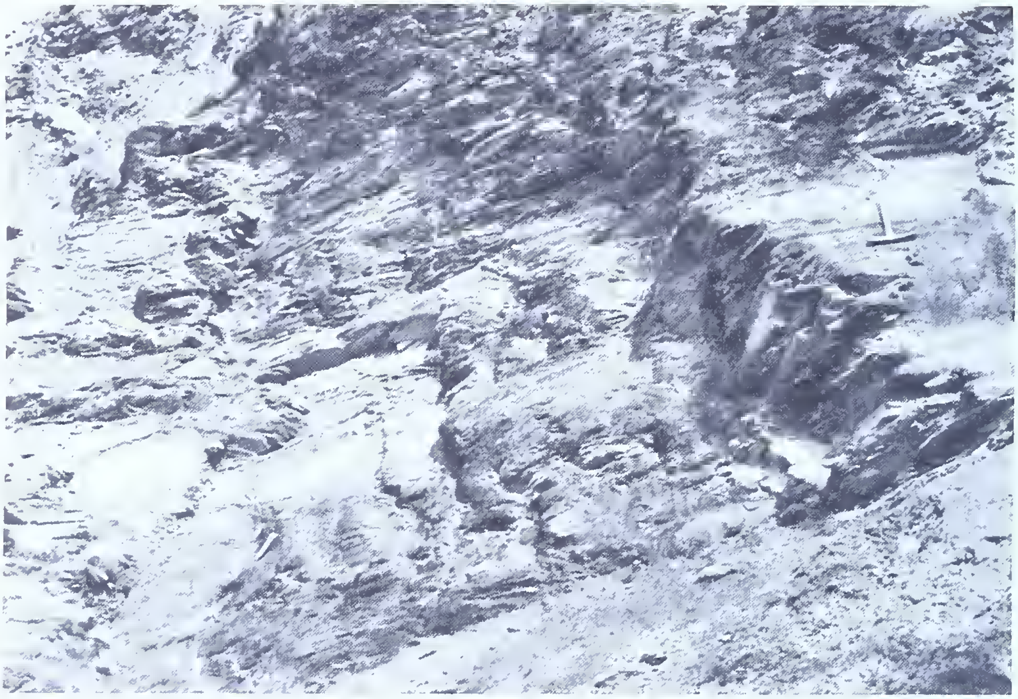

Figure 25. Marcellus Formation exposed in a small quarry north of Wardville in Greenwood Township, Perry County, site of the Wardville Devonian section (Appendix I, locality 3). Width of view is about 50 feet.

Member of the Mahantango Formation is conformable and gradational. In the upper 5 feet of the Marcellus at Cocolamus, and the upper 21 feet at Donnally Mills, the shale becomes lighter colored, slightly silty, and contains thin interbedded siltstone and very fine grained sandstone beds. Irregularities on the base of the Turkey Ridge sandstone seen in the Donnally Mills section are probably due to compaction rather than primary erosional relief, since the basal surface of the sandstone is reflected in the bedding in the underlying shale.

Age

The Marcellus Formation is Middle Devonian in age, and is correlated with the Cazenovia Stage of the Erian Series of the North American Standard Section as shown on the Correlation Chart of Devonian Rock Units in the Appalachian basin (Oliver and others, 1969). Although fossils occur in the Marcellus elsewhere in Pennsylvania (Willard and others, 1939), none were found in this quadrangle, and its Middle Devonian age assignment is based on its position with respect to the Onondaga limestone and the Mahantango Formation.

Table 15. *Thickness Values for the Marcellus Formation in Millerstown and Adjacent Quadrangles*

Locality	Quadrangle*	County	Thickness (feet)	Thickness (meters)	Source
Milltown	Loysville	Perry	75	23	Miller, 1961
Ickesburg	Loysville	Perry	110	34	Miller, 1961
Rockville	Harrisburg	Dauphin	95	29	Wood and others, 1969
Dalmatia	Millersburg	Northumberland	100	30	Hoskins, in prep.
New Bloomfield	New Bloomfield	Perry	75	23	Dyson, 1963
Millerstown	Millerstown 7½′	Perry	85	26	Willard and others, 1939
Wardville	Millerstown 7½′	Perry	106	32	Appendix I, this report

* Refers to 15-minute quadrangle unless otherwise stated.

Sedimentation

The lithology in the Marcellus indicates subaqueous deposition in water below the depth of wave base. Circulation was apparently somewhat restricted, because the carbonaceous organic matter has not been oxidized, and iron is present in the reduced form (as pyrite). The absence of current indicators implies isolation from bottom currents, and the high clay content of the sediment and relative scarcity of normal marine fossils suggest that the water was quite muddy.

Such conditions exist in modern sedimentary environments in deep, protected lagoons and in enclosed bays or marine embayments isolated from open marine water by barrier islands or reefs. The Marcellus in central New York is considered to be a back-reef lagoonal sediment, deposited in an area isolated from open marine circulation by the Onondaga reefs (Grabau, 1924). However, the Onondaga in central Pennsylvania is not a reef limestone and does not appear to be synchronous with the Marcellus. The nature of the barrier restricting circulation in the Millerstown area is not known.

The deposition of the Marcellus Formation marks the initiation of clastic sedimentation which continued intermittently through the rest of the Devonian, Mississippian, and Pennsylvanian Periods in this area.

Mahantango Formation

Name and Extent

The Mahantango Formation is the interval of sandstone, siltstone, silty claystone, and shale overlying the Marcellus Formation and underlying the Trimmers Rock-Harrell Formations (Willard, 1935a). Five members can generally be distinguished in the quadrangle. They are, in ascending order, the Turkey Ridge Member (siliceous sandstone and siltstone), the Dalmatia Member (sandstone), the Fisher Ridge Member (shale, siltstone, and sandstone), the Montebello Member (sandstone), and the Sherman Ridge Member (dominantly shale and silty claystone, with two very fine grained sandstone and siltstone intervals). The type section of the Mahantango Formation is located along Mahantango Creek, 1.5 miles (2.4 km) south of Meiserville and 1.5 miles (2.4 km) east of the Millerstown quadrangle.

The name "Turkey Ridge" was originally proposed by Willard (1935a) for a "flaggy to massive, comparatively coarse, hard, olive-gray sandstone," and was included in the Marcellus Formation because it was thought to be a sandstone lens enclosed in the black shale of the Marcellus. The black shale above the Turkey Ridge was then called the

Mahanoy Member. Miller (1961, p. 29) observed that "the Turkey Ridge and Mahanoy Members can be seen to pass by facies change into the lower part of the Montebello Formation while the Shamokin Member persists throughout the [Loysville] quadrangle as the typical Marcellus black shale." In addition, the Mahanoy was described as a laminated siltstone and black silty shale, rather than a black shale. No rocks of Marcellus lithology were observed overlying the Turkey Ridge sandstone in the Millerstown quadrangle. In the western part of the quadrangle, a laminated siltstone and black silty shale overlies the Turkey Ridge, whereas in the eastern part, correlative rocks are a uniform olive-gray silty shale. Because of the absence of rocks of typical Marcellus lithology above the Turkey Ridge Member, and because of a similarity of the Turkey Ridge sandstone to other sandstones in the Mahantango Formation, the Turkey Ridge is herein reassigned to the Mahantango Formation. The Turkey Ridge Member has not been recognized beyond the immediate vicinity of the lower Susquehanna and Juniata Valleys. A dark-gray to olive-gray sandstone is locally present directly above the Marcellus Formation in the Lykens and Pine Grove quadrangles to the east (Wood and others, 1969), and may be an eastward extension of the Turkey Ridge sandstone. This sandstone was mapped as part of the Mahantango Formation.

The Dalmatia Member is a sandstone and siltstone unit which overlies the Turkey Ridge Member in much of the Millerstown and Millersburg quadrangles. It is named for the village of Dalmatia, Northumberland County, which is situated on the east side of the Susquehanna River approximately 5 miles (8 km) east of the Millerstown quadrangle. The type section of the Dalmatia Member is located in an abandoned quarry along the Penn-Central railroad tracks about two miles (3.2 km) south of Dalmatia (Faill and others, in press). The Dalmatia Member is present on Lock, Turkey, and Wildcat Ridges and in the vicinity of East Salem.

The Fisher Ridge Member (Faill and others, in press) is named for exposures on the west end of Fisher Ridge, near Dalmatia in Northumberland County (Millersburg quadrangle). The Fisher Ridge Member encompasses all the rocks between the Turkey Ridge or Dalmatia sandstones and the Montebello Member, and is correlative with the Hamilton lower shale of Claypole (1885), the Mahantango lower shale member of Ellison (1965), and the lower shale and sandstone member of Conlin and Hoskins (1962). The Fisher Ridge Member may include the interval previously assigned to the Mahanoy Member of the Marcellus Formation (Miller, 1961; Conlin and Hoskins, 1962; Dyson, 1963, 1967). It is also correlative with part of the "lower sandstone and shale member" of the

Mahantango Formation in the Lykens and Pine Grove quadrangles (Wood and others, 1969), the Gander Run Shale Member in Huntingdon and Bedford Counties (Ellison, 1965), and the Levanna Shale Member of the Skaneateles Formation in central New York (Oliver and others, 1969).

The Montebello Member was named for exposures at Montebello Narrows on Little Juniata Creek near Duncannon in Perry County (Claypole, 1885). Although no type section was suggested for the Montebello, Claypole cited Turkey and Wildcat Ridges as being underlain by this unit. The Montebello is restricted to the Valley and Ridge province in central Pennsylvania, and correlates with the Chaneysville Sandstone Member in Bedford and Fulton Counties, and Backbone Ridge, Crooked Creek, and Donation Members in Huntingdon County (Ellison, 1965).

The Sherman Ridge Member (Miller, 1961) includes all of the Mahantango Formation above the Montebello Member; the name is derived from a ridge south of Ickesburg in Saville Township, Perry County (Loysville quadrangle). The Sherman Ridge is equivalent to the "Hamilton Upper Shale" of Claypole (1885) and the "upper shale and sandstone unit" of Conlin and Hoskins (1962), and correlates with the Frame Shale Member (Willard, 1935a) of the Mahantango Formation in Bedford County. The upper few feet of the Sherman Ridge Member are probably correlative with the Tully Member of the Harrell Formation, as described by Dyson (1963) in the adjacent New Bloomfield quadrangle.

The Sherman Ridge Member contains two distinctive intervals of very fine sandstone and siltstone which can be traced over much of the Millerstown and Millersburg quadrangles. The lower and more persistent of these is informally called the "Shadle sandstone," from exposures at the town of Shadle in Perry Township, Snyder County.

The Mahantango Formation is recognized from the Delaware Valley area of northeast Pennsylvania and southern New York to western Maryland, West Virginia,, and Massanutten Mountain in western Virginia.

Character

A pattern of asymmetric upward-coarsening cycles characterizes most of the Mahantango Formation and it is this pattern, as well as lithologic similarity, which justifies the inclusion of these separately mappable members in one formation. A cycle characteristically begins with olive-gray silty claystone and culminates in light-olive-gray siliceous sandstone and fine- to medium-grained fossiliferous or conglomeratic sandstones. The contacts between successive cycles are sharp, consisting of an abrupt decrease in grain size from a sandstone to a claystone or silty shale. The upward increase in grain size within cycles is generally gradual although small abrupt changes occur.

The cycles range in thickness from 6 feet (2 m) to 250 feet (76 m), the thinner cycles occurring predominantly in the coarser Montebello Member and the thicker cycles in the finer grained Fisher Ridge and Sherman Ridge Members. Mappable units range from 100 to 600 feet (30 to 183 m) thick and consist of several cycles, except for the two submembers of the Sherman Ridge, each of which consists of a single thick cycle.

The maximum grain size also tends to decrease laterally, so that the coarser beds at the top of each cycle become progressively thinner and finer until they merge into the lower part of another cycle. The thick, mappable cycles extend for as little as 5 miles (8 km) and as much as 30 miles (48 km). The thinner cycles presumably do not extend as far.

Because of this variable extent among the cycles, and the variation in grain size within each cycle, the lithologic sequence in the Mahantango varies from place to place. That is, at one locality a cycle may possess a Montebello lithology, whereas at another locality its finer grain size would warrant placing it in the Fisher Ridge Member. Thus, parts of the Fisher Ridge at one locality are correlative with parts of the Montebello, Turkey Ridge, or Dalmatia Members elsewhere (Figure 26). The members of the Mahantango Formation are mappable on the basis of maximum grain size and relative position within the formation. In general, those cycles which possess a maximum grain size of fine sand or larger and occur in the middle of the formation comprise the Montebello Member. The only other sandstones which approach the Montebello in coarseness are the Turkey Ridge sandstone at the base of the formation, and the medium- to coarse-grained Dalmatia sandstone which overlies the Turkey Ridge. The finer grained cycles occur predominantly between the Turkey Ridge or Dalmatia and the Montebello (Fisher Ridge Member), and above the Montebello (Sherman Ridge Member).

The Turkey Ridge Member consists of light- to medium-olive-gray, very fine to medium-grained sandstone. The sandstone is a uniform poorly sorted subgraywacke, and contains considerable quartz silt, clay, and silica cement (Table 16). The unit is medium to thick bedded and planar bedded, but is typically lacking in other internal structures. Exceptions to this are the crude low-angle crossbedding which is occasionally seen, and trough-type crossbedding which was observed at Wardville. The lithic homogeneity of the Turkey Ridge is reflected in the spheroidal or ellipsoidal exfoliation pattern which commonly develops (Figure 27). There is a medial eight-foot interval of shaly siltstone and shale in the Turkey Ridge at Donnally Mills, which may correlate with a similar, though thinner, zone in the Turkey Ridge at Cocolamus. No fossils have been found in the Turkey Ridge sandstone in the Millers-

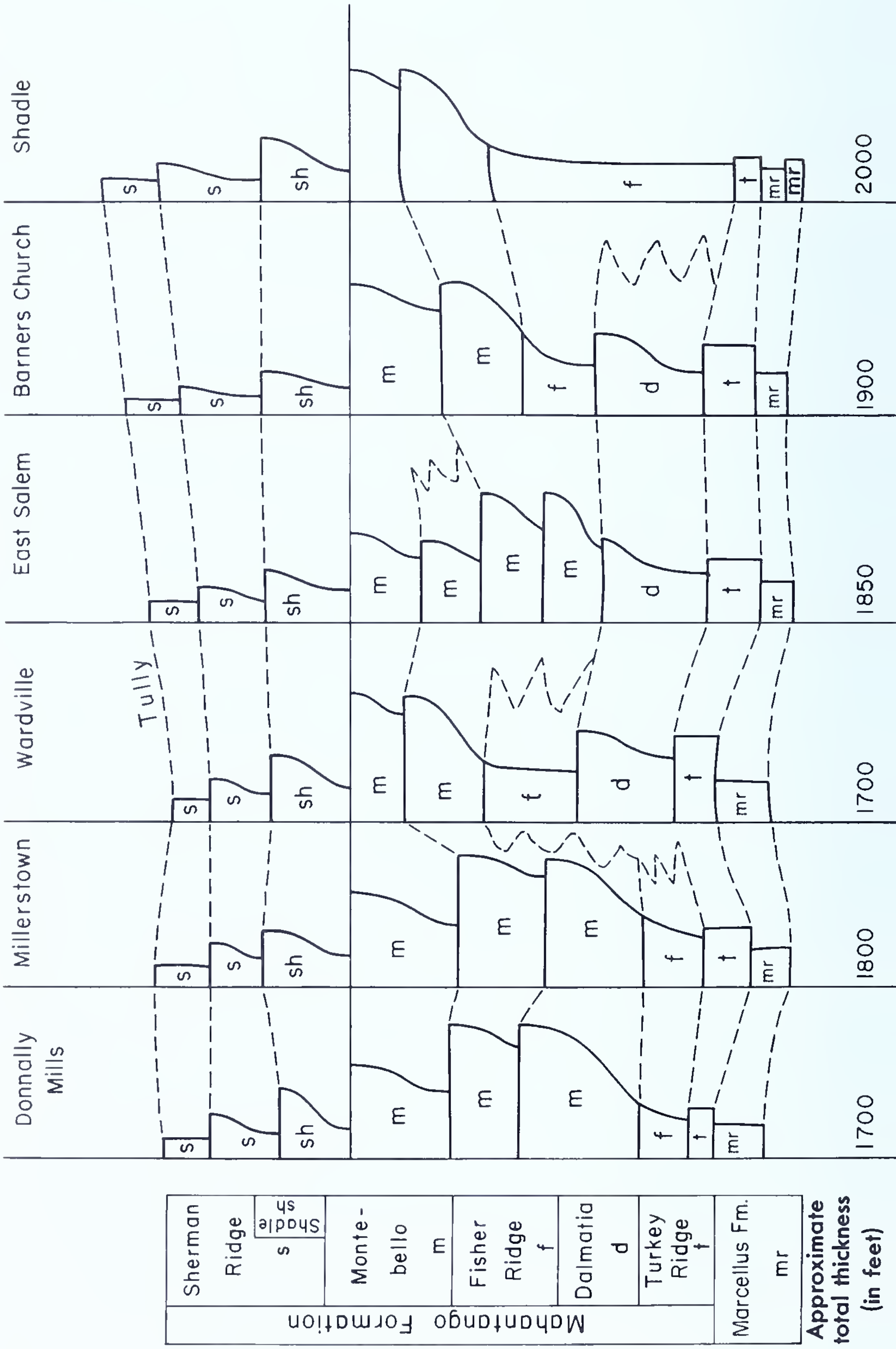
Shadle
Barners Church
East Salem
Wardville
Millerstown
Donnally Mills
Tully
2000
1900
1850
1700
1800
1700
Sherman Ridge s
Shadle sh
Montebello m
Fisher Ridge f
Dalmatia d
Turkey Ridge t
Mahantango Formation
Marcellus Fm. mr
Approximate total thickness (in feet)

Figure 26. Correlation of cyclic units in the Middle Devonian Mahantango Formation in the Millerstown quadrangle. Cycles generally become coarser upward. The width of the symbol is proportional to the grain size in the rock.

Table 16. *Petrographic Composition of the Turkey Ridge Sandstones in the Millerstown Quadrangle*

Based on analysis of eight thin sections from Thompsontown, Wardville, Donnally Mills and Mount Pleasant Mills

Constituent	Maximum (%)	Minimum (%)	Average (%)	Comment
Quartz sand	85	50	69	Sand generally subangular, except for a few well-rounded medium-sized grains; poorly sorted
Quartz silt	25	trace	11	
Clay	40	10	21	Illite-sericite
Opaque grains	5	trace	1	Not identified
Other	2	1	1	Principally feldspars and quartzite rock fragments

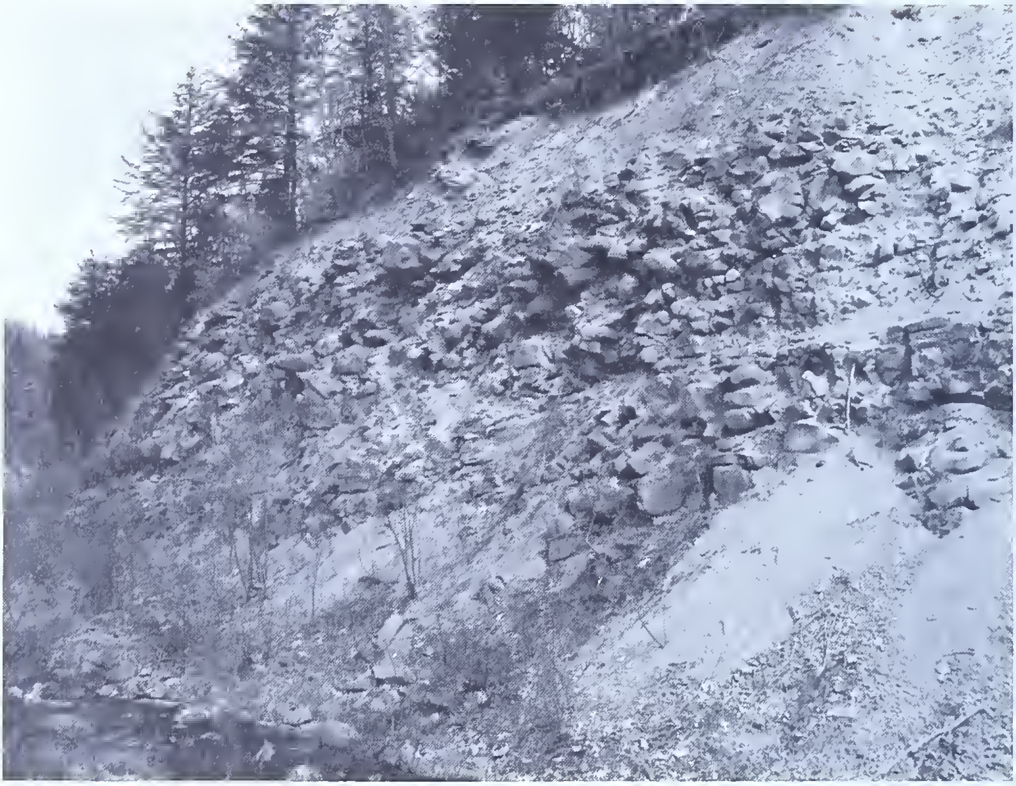

Figure 27. Turkey Ridge sandstone exposure on the east side of Delaware Creek, 1 mile north of Thompsontown on Pa. Route 235. Note tendency to fracture with an ellipsoidal exfoliation. Height of top of exposure is 41 feet above the stream. View looking northeast.

town quadrangle. For a detailed description of the Turkey Ridge lithology, see Appendix I, localities 3 and 4.

The overall geometric form of the Turkey Ridge Member is more tabular than other sandstones in the Mahantango Formation, and it maintains a fairly uniform thickness over a lateral distance of some 60 miles (97 km) from the East Waterford to Pine Grove quadrangle.

The Dalmatia Member is light-olive-gray to dark-gray, very fine, fine- and medium-grained sandstone with a few coarse and very coarse, well-rounded quartz grains scattered throughout. Bedding is thin to medium and planar. Locally, as at the Guyer farm near East Salem, this unit contains shale pebbles up to 3/4 inch (2.3 cm) in diameter, and accumulations of brachiopod shells.

The Fisher Ridge Member has a rather uniform lithology, consisting of interbedded (laminated) olive-gray, medium-gray, and medium-olive-gray shale and shaly siltstone (Figure 28). In the southwestern part of the quadrangle, the Fisher Ridge is made up of alternating laminae of medium-olive-gray, argillaceous, slightly siliceous siltstone and dark-olive-gray fissile shale. The siltstones are locally sandy with as much as 20 percent very fine, subangular to subrounded quartz sand. No fossils have been reported from the Fisher Ridge Member in this area. Weathering of the Fisher Ridge tends to accentuate the laminated character of the shale and the color tends to lighten to light olive gray or light gray.

A chemical analysis from a composite sample from the lower 125 feet of the Fisher Ridge Member at Donnally Mills is presented in Appendix II.

The Montebello Member is a thick, multicycle clastic wedge of predominantly very fine and fine-grained siliceous sandstone and a little conglomeratic sandstone. The grain size ranges from clay and silt to very coarse sand, as shown in Figure 29. Isolated grains of well-rounded, frosted, medium to coarse quartz in a fine-grained sandstone matrix are characteristic of the Montebello in some areas, as on Lock and Turkey

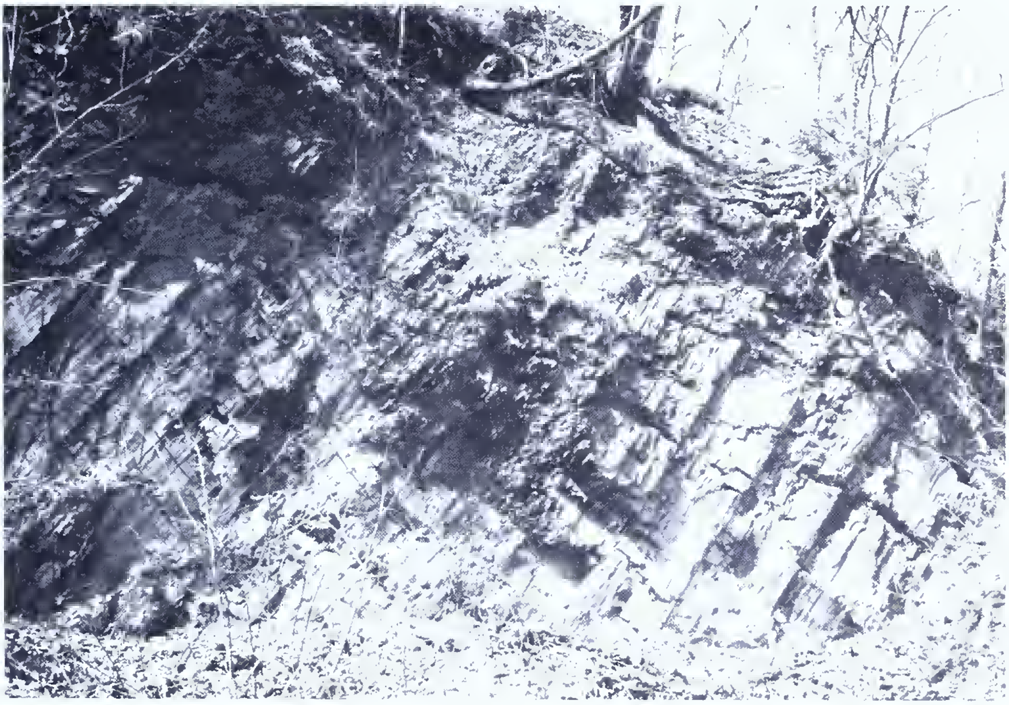

Figure 28. Fisher Ridge Member of the Mahantango Formation, exposed in a small abandoned quarry south of Donnally Mills, Pennsylvania (Appendix I, locality 5). Strata pictured here are in unit 9 of the Donnally Mills Devonian section.

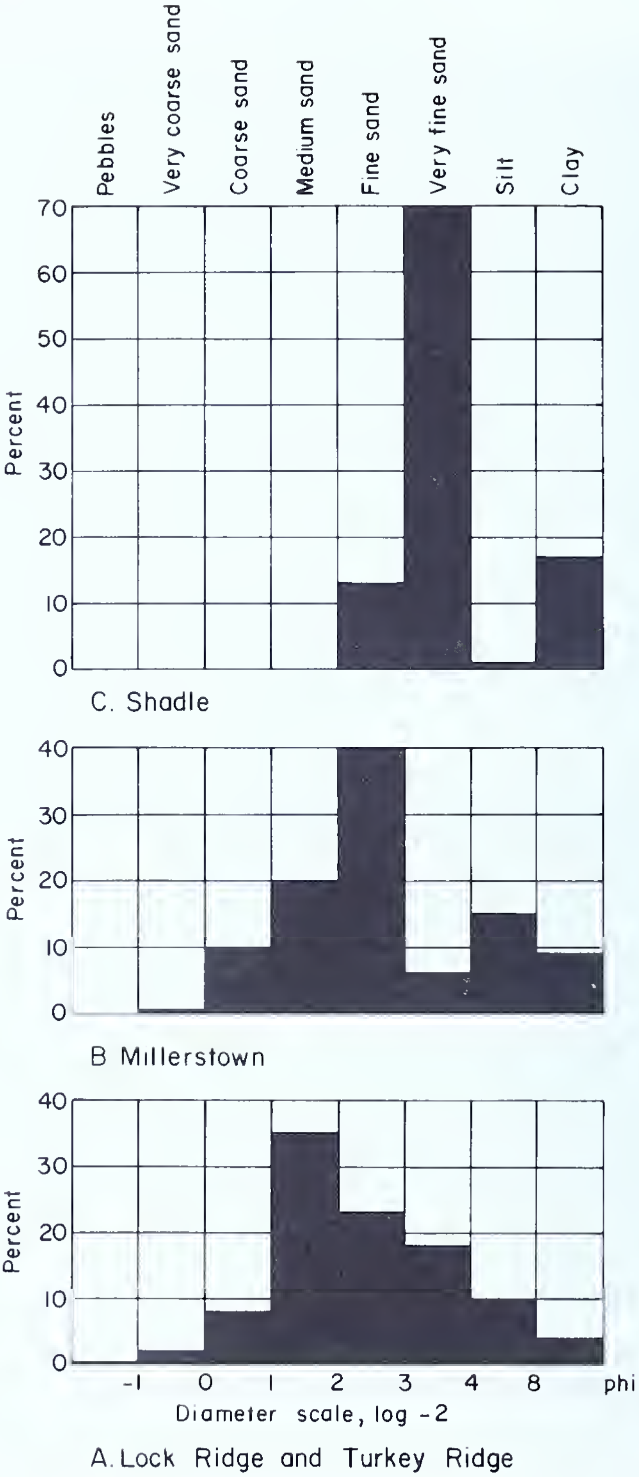

Figure 29. Histograms of grain-size distribution in the Montebello Member of the Mahantango Formation at Millerstown, Perry County, Shadle, Snyder County, and on Lock and Turkey Ridges, Juniata and Perry Counties (see Plate 3 for locations). Data for A are taken from observations at 169 stations; data for B from measured-section description by Ellison (1965) verified by field observations; data for C taken from measured-section description in Appendix I, locality 5.

Ridges. The color is predominantly light olive gray, but is locally dark to medium light gray, olive gray or dusky yellow, depending on the amount of clay present and the oxidation state of the iron oxide. On weathered surfaces, the sandstone is usually dusky yellow to pale brown.

The Montebello is very thin to thick bedded, with medium bedding predominating (Figures 30 and 31). Bedding surfaces are generally planar to slightly irregular, with poorly developed interference ripple marks common at some localities. The siltstones in the lower parts of the cycles tend to be massive.

The distinct sandstone ledges that are prominent topographically represent the tops of upward-coarsening cycles in the member (Figure 32). The lower parts of the cycles are generally graywackes to subgraywackes, with interstitial clay matrix comprising 20 to 40 percent of the rock. Other constituents, mainly chert and feldspar, are present only in trace amounts. The upper beds are cleaner, better sorted orthoquartzites. The sand grains are nearly all subrounded to subangular quartz, tightly cemented with silica (and locally calcite). Thin lenses of very coarse sandstone (locally conglomeratic) in the upper parts of the cycles consist of

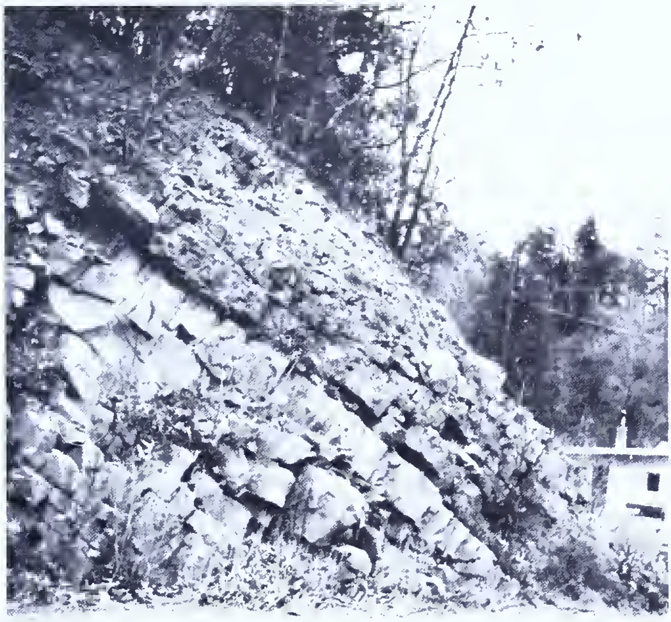

Figure 30. Upper beds of the Montebello Member exposed along Pa. Route 104 at Shadle, Pennsylvania. Sandstone beds seen here are in units 24 and 25 of the Shadle Devonian section, locality 5. Top of thick-bedded sandstone is the contact of the Montebello and Sherman Ridge Members of the Mahantango Formation.

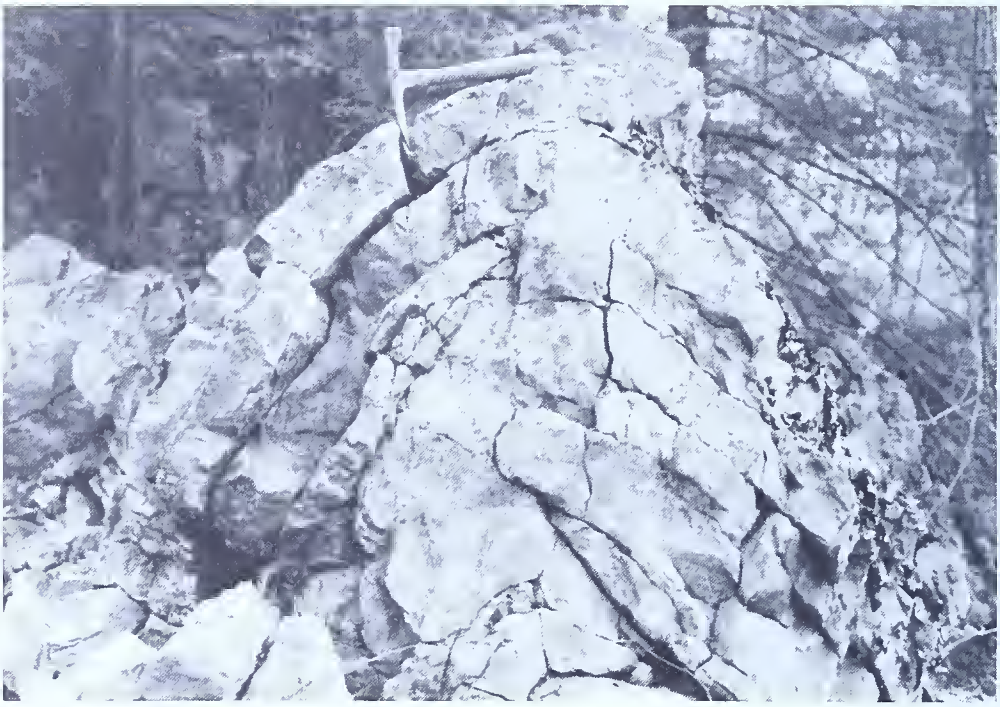

Figure 31. Faulted kink-band fold in the Montebello sandstone exposed northeast of the confluence of Cranes Run and Cocolamus Creek, 0.6 mile north of Wardville. Several of these small folds occur in the Mahantango on Lock and Turkey Ridges in the Wardville area. Fold axis plunges N67E, 7° and slickensides on the prominent vertical fracture (roughly parallel to the plane of the photograph) plunge S16E, 9°.

well-rounded to subrounded clasts of quartz, quartzite, siltstone, and metamorphic rock fragments. Maximum observed pebble size was 3/8 inch (1 cm) and the maximum conglomerate thickness was 20 inches (50 cm).

The sandstones in the upper parts of the cycles are locally fossiliferous, with large numbers of brachiopods, molluscs, and crinoids (Table 17) occurring both as solitary individuals and concentrated in lenses. Casts of fossil wood, plant material, and bone fragments occur in the Montebello sandstone at Wardville and East Salem.

Thin zones and lenses of chamosite oolites occur in the Mahantango Formation at Amity Hall, Girtys Notch, and Rockville in the adjacent New Bloomfield, Millersburg, and Harrisburg quadrangles (Faill and others, in press). These oolites occur in dark-gray silty shale at the tops of coarsening-upward cycles, and have formed about nuclei of quartz sand or other broken oolites, indicating development during sedimentation

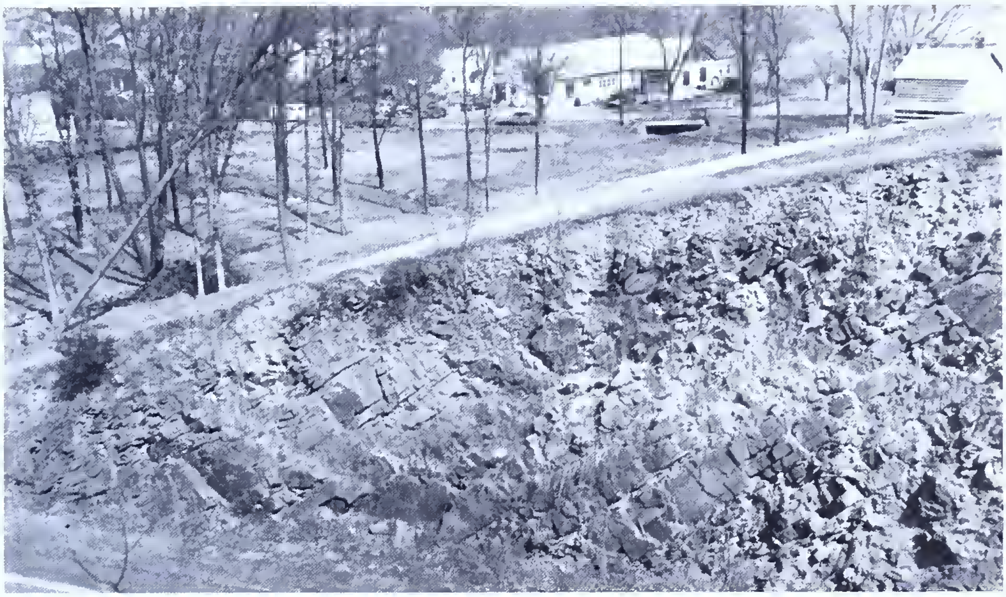

Figure 32. Montebello sandstone exposed in a roadcut on Pa. Route 235 at East Salem, Juniata County. The alternating medium-bedded, thin-bedded, and nonbedded intervals correspond to fine-grained sandstone, very fine grained sandstone, and siltstone beds. View is looking eastward, and the highest beds mark the top of the Montebello Member.

and prior to burial. According to Sheppard and Hunter (1960) the oolites are composed of concentric shells of chamosite, collophane, or alternating layers of chamosite and collophane. Although no chamosite oolites have been found in the Millerstown quadrangle, their occurrence in the adjacent quadrangles suggests that they may also be present here.

The Sherman Ridge Member is a light-olive-gray fossiliferous silty claystone, containing two complete upward-coarsening cycles and one incomplete(?) upward-coarsening cycle. The silty claystone is generally massive, and consistently displays an ellipsoidal or spheroidal exfoliation (Figure 33). In the complete cycles, the grain size increases gradationally toward the top to siltstone (upper cycle) or sandstone (lower cycle, "Shadle sandstone") (see Figures 34 and 35). The coarser beds in both cycles are argillaceous, siliceous, often slightly calcareous graywacke having a clay content of 40 to 45 percent. These beds are highly burrowed, and small, broken shell fragments occur in calcareous samples of the lower cycle or "Shadle sandstone." Silica is the dominant cementing material and the effective porosity is nil. See Appendix I, locality 5 for a description of the "Shadle sandstone."

Table 17. *List of Species Collected from the Mahantango Formation in the Millerstown Quadrangle*[1]

	Locality							
	Wardville (Dmm)	Mt. Pleasant Mills (Dmm)	Cocolamus (Dmm)	East Salem (Dmm)	Richfield (Dmm, Dms)	Kellerville (Dms)	Seven Stars (Dms)	Millerstown (Dmm)[2]
Phylum								
Coelenterata								
Favosites sp.							X	X
Pleurodictyum stylopora (Eaton)					X		X	
unidentified rugose coral			?					
Phylum								
Brachiopoda								
Camarotoechia congregata (Conrad)		?						X
"*Chonetes lepidus*" (Hall)			X					
Delthyris sculptilis (Hall)			X		X			
Devonochonetes coronatus (Conrad)							X	X
Devonochonetes scitulus (Hall)			X			X	X	X
Devonochonetes syrtalus (Conrad)								X
Longespina mucronatus (Hall)		X			X			X
Mediospirifer audaculus (Conrad)								X
Mediospirifer cf. *M. belliplicata*								X
Mediospirifer bellitropis (Ellison)	X							X
Mediospirifer cf. *M. dromgoldi*								X
Mediospirifer millerstownensis (Ellison)	X				X			X
Mediospirifer sp.			X					
Mucrospirifer mucronatus (Conrad)			X		X	X	X	X
Paraspirifer acuminatus (Conrad)	X							X
Protoleptostrophia perplana (Conrad)			X				X	
Retichonetes marylandicus								X
Schuchertella variabilis (Prosser and Kindle)							X	X
Spinocyrta granulosa (Conrad)					X			X
Spirifer tullius								X
Spirifer sp.				X				X
Tropidoleptus carinatus (Conrad)			X					X
Phylum								
Mollusca								
Class								
Cephalopoda								
Bactrites? aciculum (Hall)						?	X	
Spyoceras nuntium (Hall)					X			
unidentified species				X			X	

Table 17. *(Continued)*

	Locality							
	Wardville (Dmm)	Mt. Pleasant Mills (Dmm)	Cocolamus (Dmm)	East Salem (Dmm)	Richfield (Dmm, Dms)	Kellerville (Dms)	Seven Stars (Dms)	Millerstown (Dmm)[2]
Class Gastropoda								
bellerophontid gastropod								X
Bembexia laevis (Ellison)		X		X		X	X	
Bembexia sulcomarginata (Conrad)			X	X				X
Cyclonema sp.?							X	
Cyrtolites (*Cyrtonella*) *mitella*							X	
Holopea macrostomus (Hall)					?			
Ianthinopsis? sp.								X
Loxonema cf. *L. delphicola*								X
Class Pelecypoda								
Nuculites triqueter (Conrad)							X	
Orthonota undulata (Conrad)							X	
Paleoneilo constricta (Conrad)							X	
Sphenodus sp.?								X
unidentified species						X	X	
Class Pteropoda								
Tentaculites attenuatus Hall			X			?		X
Phylum Arthropoda								
Class Trilobita								
Greenops bootni var. *calliteles* (Green)			X		X		X	
Phacops rana (Green)								X
Trimerus (*Dipleura*) *dekayi* (Green)			X					
Phylum Echinodermata								
crinoid columnals	X		X	X	X		X	X
Phylum Bryozoa								
Tacniopora exigua								X

Question mark indicates identification is uncertain.

[1] Fossil identifications by Stephen S. Herr, Donald M. Hoskins, and the authors.

[2] List for Millerstown quadrangle includes species collected by Ellison (1965).

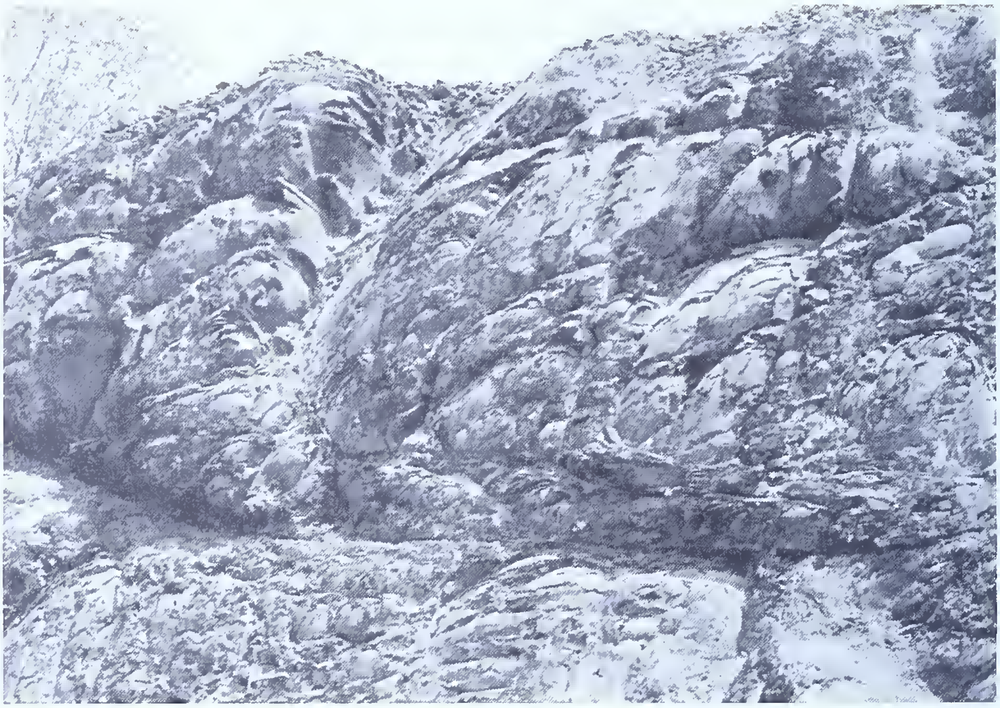

Figure 33. Sherman Ridge Member of the Mahantango Formation exposed in an active quarry at Kellerville, Juniata County. The Sherman Ridge is quarried here for use in road construction. Note the irregular fracture pattern and characteristic spheroidal exfoliation.

A bluish-black adamantine coating of manganese oxide (wad) occurs on the bedding planes and fracture surfaces of the claystones, although the manganese oxide content is quite small (Appendix II).

The finer grained parts of the Sherman Ridge Member are fossiliferous, with dense populations of brachiopods, crinoids, molluscs, trilobites, and a few corals (Table 17). A detailed paleontological study of the Mahantango Formation in central and southern Pennsylvania by Ellison (1965) included several measured sections in the vicinity of the Millerstown quadrangle. Other faunal lists for the Mahantango in central Pennsylvania have been published by Willard (1935a, 1938) and Willard and others (1939). Good fossil-collecting localities exist in the Mahantango Formation at Wardville, East Salem, Millerstown, and Shadle. The greatest density of fossils and largest specimens are concentrated in the upper few feet of most of the cycles in the Montebello Member.

Outcrop Area and Thickness

The Mahantango Formation is present in the Millerstown quadrangle in four linear belts, each of which underlies a prominent ridge adjacent to the Upper Silurian valleys on the flanks of the two anticlinoria.

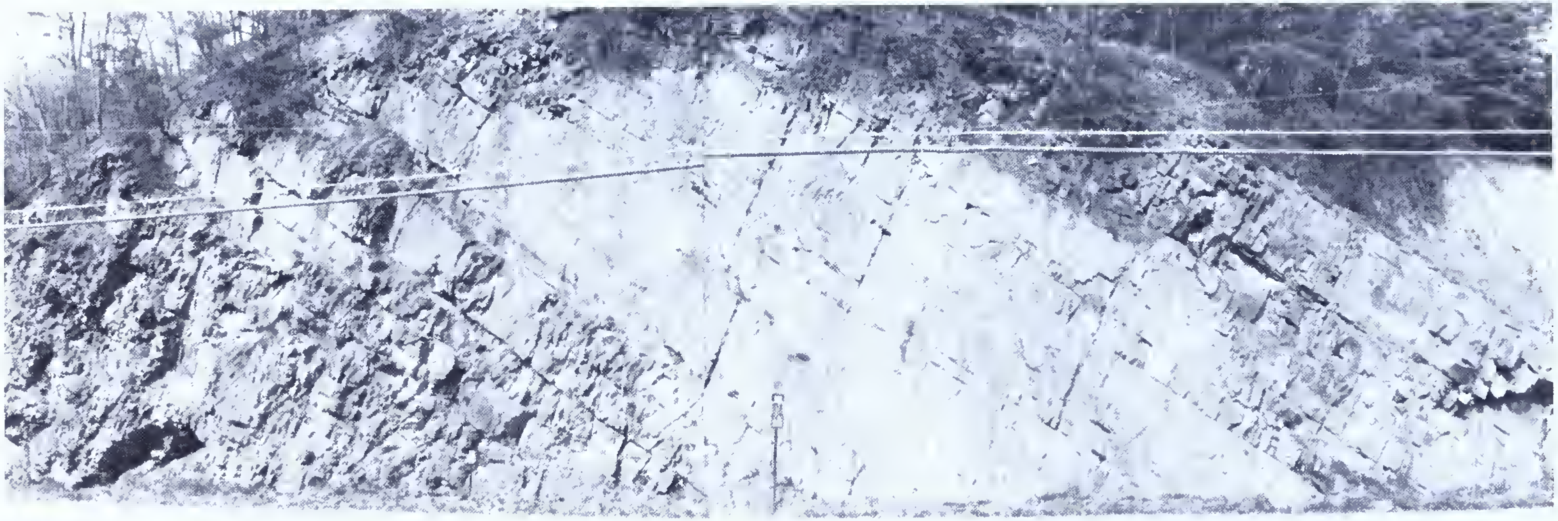

Figure 34. Lower cycle or ''Shadle sandstone'' of the Sherman Ridge Member exposed on Pa. Route 104 at Shadle, Snyder County. View looking east. The prominent ledge at the right marks the top of the ''Shadle sandstone.'' Units 8 through 11 of the Shadle Devonian section (Appendix I, locality 4) are seen in this view.

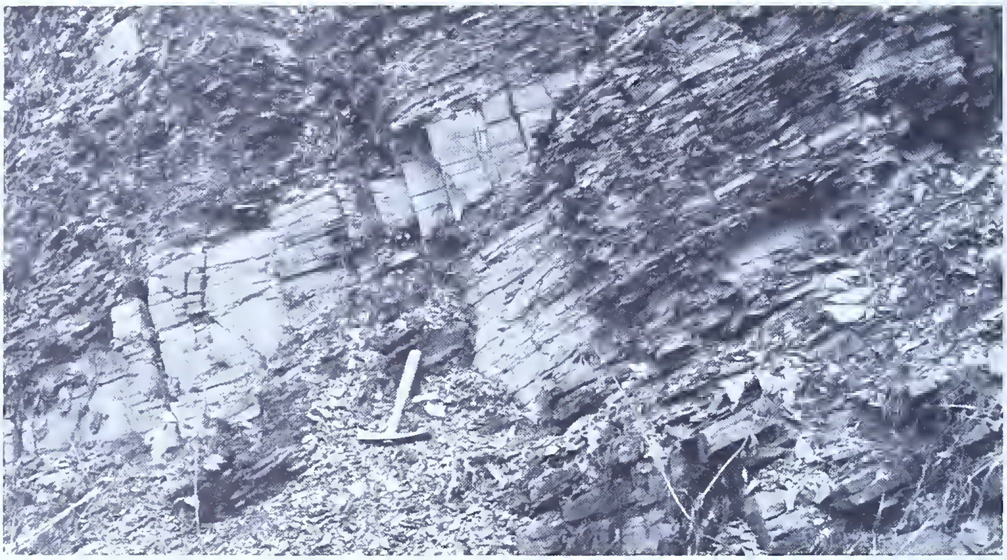

Figure 35. Exposure of the upper silty zone in the Sherman Ridge Member at Maze, Juniata County. Interbedded siltstone and very fine grained crossbedded sandstone.

The Montebello sandstone generally occupies the summit of these ridges, and the Turkey Ridge Member normally occurs on the scarp slopes. Different Montebello sandstone beds alternately occupy the crestal position because of the lateral variation in the cycles and changes in dip. In the northern part of the quadrangle, the ridges underlain by the Montebello are lower because the sandstones are fewer, thinner, and less resistant. As a result, the Turkey Ridge Member forms a ridge of its own, separated by narrow linear valleys from the adjacent, usually higher, Montebello and Old Port ridges.

Variability in crestal units is demonstrated on Wildcat Ridge, for example, where two resistant Montebello sandstone ledges form the crest near the western end of the ridge. A distinctive conglomeratic sandstone bed, which is found on the dip slope below the summit near Millerstown, gradually assumes the crestal position as these beds are traced eastward across the quadrangle, whereas the underlying sandstone ledges disappear. A similar change occurs on Lock Ridge to the north. The Fisher Ridge Member, which is less resistant to erosion, generally occurs on the scarp slope of the Montebello ridges (in the southern part of the quadrangle) or under the valley between the Montebello and Turkey Ridge ridge (in the northern part).

The Sherman Ridge Member underlies the dip slopes of the Montebello ridges, occasionally developing terraces on the resistant sandstones in the tops of its cycles.

The only complete exposure of the Turkey Ridge Member in the area is at Donnally Mills, but good exposures are also present along Delaware Creek a mile (1.6 km) north of Thompsontown (Figure 27). There is no complete exposure of the Dalmatia Member in the quadrangle, but the lower 180 feet of it can be seen in the Wardville Devonian section (Appendix I, locality 3). The Fisher Ridge Member is best exposed along Mahantango Creek south of Meiserville (Dalmatia quadrangle), in the type section for the Mahantango Formation. Good exposures of the Mahantango Member are present on the end of Raccoon Ridge opposite Millerstown, along the east side of Cocolamus Creek north of Wardville (Figure 31), and at East Salem (Figure 32). The Sherman Ridge is exposed in several small quarries opened in this member, as on Raccoon Ridge opposite Millerstown, at Kellerville (Figure 33), Seven Stars, and Shadle (Figure 34).

The Mahantango Formation is approximately 1700 to 2050 feet (518 to 625 m) thick in the quadrangle. Because of the lateral variations in the cycles, the thickness of the formation and its individual members varies greatly. The Turkey Ridge is about 100 feet (30 m) thick over much of the quadrangle, ranging from 79 feet (24 m) at Wardville and 124 feet (38 m) at Donnally Mills to less than 20 feet (6 m) at Mt. Pleasant Mills. The maximum thickness of the Dalmatia Member is estimated at 305 feet (93 m). The Fisher Ridge Member is absent in the southwest but is up to 700 feet (213 m) thick at Mt. Pleasant Mills. The Montebello is 900 feet (274 m) in the south and thins to 200 feet (61 m) in the northern part of the quadrangle. The Sherman Ridge Member has a relatively constant thickness throughout the quadrangle (500 to 700 feet, 152 to 213 m). Measurements from surrounding quadrangles suggest that the interval equivalent to the Tully Member is from zero to 17 feet (5.2 m) thick in this area.

Regionally, the Mahantango Formation maintains a fairly constant thickness in central Pennsylvania. Most of the member thickness changes which occur within the formation are accompanied by compensatory changes in other members. The dominant change is the thinning of the Montebello Member from more than 900 feet (275 m) in the Marysville-Rockville area in southern Perry County to zero in northern Snyder County, as shown in isopach maps by Willard and others (1939) and Faill and others (in press). Another isopach map, by Wood and others (1969), also shows a northward thinning of the Montebello in the anthracite region. Each isopach map shows fan-shaped sandstone bodies with their apexes in the south some thirty miles apart.

The thickness of the Mahantango Formation and its members in the vicinity of the Millerstown quadrangle is presented in Table 18.

Table 18. *Thickness Values for the Mahantango Formation and Its Members in the Vicinity of the Millerstown Quadrangle*[1]

			Thickness						
Locality	Quadrangle**	County	Turkey Ridge Member	Dalmatia Member	Fisher Ridge Member	Montebello Member	Sherman Ridge Member	Total Mahantango Formation	Source
Millerstown	Millerstown 7½′	Perry	—	—	—	641′ (195 m)	558′ (170 m)	—	Ellison, 1965
Turkey Ridge, Wardville	Millerstown 7½′	Perry	79′ (24 m)	180′ (55 m) (partial)	65′ (20 m)	115′ (35 m)			this report, locality 3
Mahantango Ck., Meiserville	Millersburg	Juniata, Snyder	—	—	340′ (104 m)	446′ (136 m)	459′ (140 m)	1,245′ (380 m)	Ellison, 1965
Shadle	Millersburg	Snyder	—	—	—	269′ (82 m) (partial)	523′ (159 m)	—	this report, locality 4
Dalmatia	Millersburg	Northumberland	—	305′ (93 m) (partial-base covered)	452′ (138 m)	378′ (115 m)	—	—	Hoskins, in prep.
Various localities	Lykens and Pine Grove	Dauphin, Lebanon, Schuylkill	90′ (27 m)	—	0–700′ (0–213 m)	290–710′ (88–216 m)	900–1,250′ (274–380 m)	1,200–2,190′ (366–668 m)	Wood and others, 1969
Donnally Mills	Millerstown 7½′	Perry	124′ (38 m)	—	191′ (58 m)	—	—	—	this report, locality 5
Various localities	Millerstown	Juniata, Snyder, Perry	100′ (30 m)	100–300′ (30–90 m)	0–700′ (213 m)	200–900′ (61–274 m)	500–700′ (152–213 m)	1,700–2,050′ (518–625 m)	this report
Not specified	Mifflintown	Juniata	100–150′ (30–46 m)	—	*75′ (23 m)	—	—	1,100′ (335 m)	Conlin and Hoskins, 1962
East Waterford	East Waterford	Juniata	103′ (31 m)	—	—	—	—	—	Arndt and others, 1959
Not specified	Loysville	Perry	—	—	—	1,000′ avg. (305 m)	600′ (183 m)	—	Miller, 1961
Lutman Run	New Bloomfield	Perry	66′ (20 m)	—	—	—	—	—	Dyson, 1963
White Run, Newport	New Bloomfield	Perry	91′ (28 m)	—	*100–120′ (30–37 m)	—	—	—	Dyson, 1963
Not specified	New Bloomfield	Perry	—	—	*100–120′ (30–37 m)	1,000–1,100′ (305–335 m)	500′ (152 m)	—	Dyson, 1963
Marysville	Harrisburg	Perry	—	—	—	800′ (244 m)	—	—	Claypole, 1885

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[1] Missing data indicates intervals not measured.

* Mahanoy Member.

** Refers to 15-minute quadrangle unless otherwise stated.

Formation Boundaries

As mentioned above, the lower contact of the Turkey Ridge Member is both conformable and gradational. Where the Dalmatia Member is absent, the upper contact of the Turkey Ridge sandstone (with the Fisher Ridge Member) is sharp and conformable, as seen at Donnally Mills (Appendix I, locality 4). The contacts of the Dalmatia sandstone have not been observed. The upper contacts of the Montebello and "Shadle" sandstones are sharp and conformable (Figure 30). The top of the Mahantango Formation (Sherman Ridge Member) and its contact with the overlying Harrell Formation are not exposed in the quadrangle. However, bedding on opposite sides of the contact tends to be parallel, indicating either conformity or paraconformity at the contact.

Age

The Mahantango Formation is Middle Devonian in age. The Turkey Ridge, Dalmatia and Fisher Ridge Members correlate with part of the Cazenovia Stage of the Erian Series. The Montebello Member is equivalent to most of the Cazenovia Stage and part of the later Tioughnioga Stage. The Sherman Ridge Member is equivalent to the remainder of the Tioughniogan Stage and a part of the Taghanic Stage, the latest stage of the Erian Series. Correlative units to the Mahantango Formation in the New York Section are the Skaneateles, Ludlowville, and Moscow Formations of the Hamilton Group (Oliver and others, 1969). Calcareous shales in the upper few feet of the Mahantango are correlative with the Tully limestone, which is the uppermost unit in the Middle Devonian.

Sedimentation

The regional stratigraphic relationships, overall geometric form, sequence of rock types, internal structures, and fauna of the Mahantango Formation are indicative of deposition along a prograding marine shoreline. Furthermore, the radial pattern of thinning and fining in most of the sandstone units, and the occurrence of coarsening-upward ("reverse-graded") cycles in known deltaic sequences (deRaaf and others, 1965; Gardiner, 1970; Gould, 1970; Oomkens, 1970; and Weber, 1971) suggest that the Mahantango Formation is a product of deltaic sedimentation.

Sedimentation at the beginning of each cycle began well below wave base with deposition of clay and silt, which became progressively coarser, culminating in the deposition of clean, fine- to medium-grained sand (with occasional quartz pebbles) at the top. The upward increase in grain size, sorting, and winnowing of the sediment within the cycles suggests a progressive increase in the effectiveness of wave and current action, perhaps reflecting a gradual decrease in water depth as sediment accumulated. The concentration of brachiopods and molluscs in the upper parts of the cycles suggests that during the late phases of the cycles conditions were favorable for these organisms.

Typical examples of "complete" deltaic sequences have tidal-flat, marsh, and fluvial deposits overlying the marine sediments (Scruton, 1960; Visher, 1965). The Mahantango cycles are apparently incomplete because each cycle is abruptly terminated at the shallow marine phase of the cycle, with a subsequent return to deeper, quiet-water sedimentation. The interruption of sediment input at a given locality and the repetition of cycles may have resulted from the abandonment of distributary outlets with a concomitant transfer of sedimentation to other areas of the delta. Such a shift would result in an abrupt decrease in sediment supply at a site which had been receiving large amounts of relatively coarse sediment. Deposition would resume only after a period of gradual subsidence had enabled deeper water to return, initiating the development of a new cycle over the previous one. The absence of supratidal and fluvial deposits indicates that the sediment supply to the delta was never great enough, with respect to the rate of sediment dispersal and subsidence, for subaerial conditions to be established.

Kaiser (1971, 1972) recognized the cyclic nature of Mahantango sedimentation, and suggested that the repetition of cycles was the result of successive growth and abandonment of different delta lobes.

The repetition of cycles might also be attributed to intermittent uplift in the source area or climatic cycles in a static highland source area. The previously described model is favored, however, because the individual Mahantango sandstones are not considered extensive enough to reflect either tectonic events or climatic cycles.

Isopach maps of the Montebello sandstone (Willard and others, 1939; Wood and others, 1969; Faill and others, in press) exhibit a typical delta-fan shape with two separate apparent "point sources" to the south and southeast. These "point sources" probably represent the points at which the major drainage debouched onto the delta. The presence of quartzite rock fragments indicates that sedimentary (or metasedimentary) rocks were exposed in the source area. Willard (1935a) has suggested that some of the Turkey Ridge sand was derived from reworked Oriskany (Ridgeley) sandstone.

The relationship of the Turkey Ridge Member to the rest of the Mahantango is problematic; although lithologically similar to the other Mahantango sandstones, the Turkey Ridge sandstone is more tabular in form, is not fossiliferous, and lacks the systematic vertical variation in grain size seen in the Montebello and Sherman Ridge Members. The Turkey Ridge probably represents a sudden increase in rate of sediment supply in the relatively stagnant, restricted basin in which the Marcellus shales had accumulated and thus marks the beginning of sedimentation on the Mahantango delta.

The Dalmatia Member is lithologically similar to the Montebello (although it lacks the conglomeratic sandstone) and exposures in the Dalmatia quarries establish it as the first upward-coarsening cycle of the Mahantango.

The Fisher Ridge Member represents more distal portions of the early delta, and grades southward into the lowest Montebello sandstones. Through time, the nearshore part of the delta (Montebello) built outward (cyclically) and northward over the Fisher Ridge sediments. The uppermost cycles of the Montebello possess the greatest northward extent. North of the Millerstown quadrangle it is represented only by two thin, rather fine grained cycles.

The beginning of the Sherman Ridge deposition marks a significant decrease in sediment input to the area (relative to rate of subsidence), although the cyclic pattern persisted. The two Sherman Ridge cycles have a greater thickness and areal extent than most of the Montebello cycles, and there is a similar northward decrease in maximum grain size. The large communities of pelagic, benthonic, and burrowing organisms suggest that the Sherman Ridge was deposited in a more normal, offshore marine environment.

The widespread and diverse marine fauna reported from the Tully in central Pennsylvania suggests that the Tully was formed in a quiet, normal marine environment. Grabau (1917) and Heckel (1969) studied the petrography of the Tully, and found evidence that the carbonate mud was derived from a northern source in central New York, whereas the terrigenous clay in the Tully was contributed by a source which lay to the southeast.

Susquehanna Group

The Susquehanna Group (Miller and Conlin, 1961), originally named the Susquehanna Series by Ashley (1923), is a thick deposit of sandstone, siltstone, and shale above the Hamilton Group which includes, in ascending order, the Harrell, Trimmers Rock, and Catskill Formations. Susquehanna Group is a useful term for designating beds or outcrops which have not been correlated at the formation level. In some areas difficulties arise over the placing of formation boundaries within the Susquehanna Group, and in these cases the group name is applicable.

Trimmers Rock—Harrell Formations

Name and Extent

The lowest part of the Susquehanna Group was referred to as the Vergent Flags (Rogers, 1858) and was considered to be equivalent to the

Portage Formation in New York. The overlying pre-Catskill rocks were the Vergent Shales, equivalent to the Chemung Group of New York. Butts (1918) proposed the Harrell Formation for a 250-foot-thick (76 m) sequence of gray and black shale which overlies the Hamilton Group (and Tully limestone) in Blair and Huntingdon Counties. The Harrell was overlain by 1000 feet (305 m) of Braillier; 2000 feet (610 m) of "Chemung" rocks lay between the Braillier and the overlying Catskill Formation. Willard (1935b) defined two formations between the Mahantango and Catskill Formations, the Rush Formation (containing the Tully and Burket Members) and the Fort Littleton Formation (containing, in ascending order, the Harrell, Braillier, Losh Run, Trimmers Rock, and Parkhead Members). Hoskins (1963) discarded Willard's terminology, reinstating Butts' original definition of Harrell and combining the remainder of the Fort Littleton into the Trimmers Rock Formation and the Braillier Formation, undivided (see Figure 36).

In the Millerstown quadrangle, the Tully and Burket Members and the Braillier Formation have not been recognized as a separate lithologic unit; the shales at the base of the Susquehanna Group (Harrell) grade into the shale-siltstone sequence characteristic of the Trimmers Rock. Because of poor and infrequent exposures of the Harrell, the Harrell and Trimmers Rock Formations have been mapped as a single undivided unit (Plate 1).

The Harrell Formation extends from central Pennsylvania into western Maryland and West Virginia. The Trimmers Rock Formation is recognized in central and eastern Pennsylvania from the lower Juniata River valley to the Delaware Valley.

A chemical analysis and clay-shale test report of shales from the Harrell Formation in Liverpool Township appear in Appendix II and Appendix III.

Character

The Harrell Formation consists of dark- to light-olive-gray and medium-light-gray silty shale which is generally noncalcareous, very thin bedded, and breaks with a blocky or splintery fracture. There are a few thin beds of light-gray argillaceous and siliceous siltstone in the upper part. The Harrell is barren of fossils, but excellent examples of groove casts are occasionally seen (Figure 37).

The Trimmers Rock Formation is predominantly light-olive-gray and medium-gray siltstone and silty shale, with minor interbedded very fine sandstone in the upper part (Figure 38). The siltstones are graywackes (up to 40 percent clay content) generally cemented with silica (and locally carbonate), and contain burrows filled with fine silt. The shales are poorly fissile and commonly grade into silty claystones. The sand-

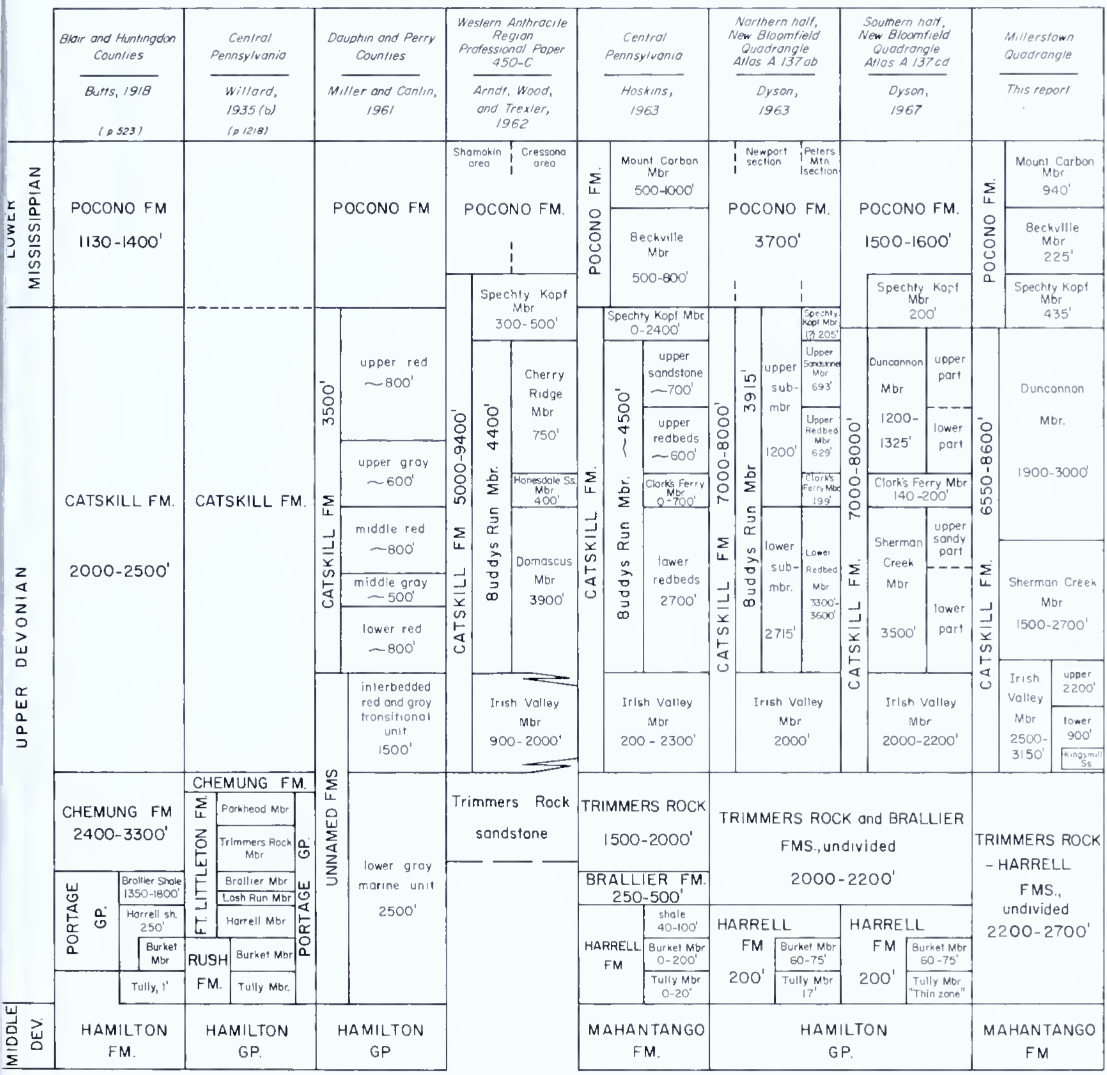

Blair and Huntingdon Counties
Butts, 1918
(p 523)
Central Pennsylvania
Willard, 1935 (b)
(p 1218)
Dauphin and Perry Counties
Miller and Conlin, 1961
Western Anthracite Region Professional Paper 450-C
Arndt, Wood, and Trexler, 1962
Central Pennsylvania
Hoskins, 1963
Northern half, New Bloomfield Quadrangle Atlas A 137ab
Dyson, 1963
Southern half, New Bloomfield Quadrangle Atlas A 137cd
Dyson, 1967
Millerstown Quadrangle
This report
LOWER MISSISSIPPIAN
UPPER DEVONIAN
MIDDLE DEV.
POCONO FM
1130-1400'
CATSKILL FM.
2000-2500'
CHEMUNG FM
2400-3300'
PORTAGE GP.
Brallier Shale
1350-1800'
Harrell sh.
250'
Burket Mbr
Tully, 1'
HAMILTON FM.
CATSKILL FM.
CHEMUNG FM.
FT. LITTLETON FM.
Parkhead Mbr
Trimmers Rock Mbr
Brallier Mbr
Losh Run Mbr
Harrell Mbr
PORTAGE GP.
RUSH FM.
Burket Mbr
Tully Mbr.
HAMILTON GP.
POCONO FM
CATSKILL FM 3500'
upper red
~800'
upper gray
~600'
middle red
~800'
middle gray
~500'
lower red
~800'
UNNAMED FMS
interbedded red and gray transitional unit
1500'
lower gray marine unit
2500'
HAMILTON GP
Shamokin area
Cressona area
POCONO FM.
CATSKILL FM 5000-9400'
Spechty Kopf Mbr
300-500'
Buddys Run Mbr. 4400'
Cherry Ridge Mbr
750'
Honesdale Ss. Mbr
400'
Damascus Mbr
3900'
Irish Valley Mbr
900-2000'
Trimmers Rock sandstone
POCONO FM.
Mount Carbon Mbr
500-1000'
Beckville Mbr
500-800'
CATSKILL FM.
Spechty Kopf Mbr
0-2400'
Buddys Run Mbr. ~4500'
upper sandstone
~700'
upper redbeds
~600'
Clark's Ferry Mbr
0-700'
lower redbeds
2700'
Irish Valley Mbr
200 - 2300'
TRIMMERS ROCK
1500-2000'
BRALLIER FM.
250-500'
HARRELL FM
shale
40-100'
Burket Mbr
0-200'
Tully Mbr
0-20'
MAHANTANGO FM.
Newport section
Peters Mtn. section
POCONO FM.
3700'
CATSKILL FM 7000-8000'
Buddys Run Mbr 3915'
upper sub-mbr
1200'
Spechty Kopf Mbr
(?) 205'
Upper Sandstone Mbr
693'
Upper Redbed Mbr
629'
Clark's Ferry Mbr
199'
lower sub-mbr.
2715'
Lower Redbed Mbr
3300'-3600'
Irish Valley Mbr
2000'
TRIMMERS ROCK and BRALLIER FMS., undivided
2000-2200'
HARRELL FM
200'
Burket Mbr
60-75'
Tully Mbr
17'
HAMILTON GP.
POCONO FM.
1500-1600'
Spechty Kopf Mbr
200'
CATSKILL FM. 7000-8000'
Duncannon Mbr
1200-1325'
upper part
lower part
Clark's Ferry Mbr
140-200'
Sherman Creek Mbr
3500'
upper sandy part
lower part
Irish Valley Mbr
2000-2200'
HARRELL FM
200'
Burket Mbr
60-75'
Tully Mbr
"Thin zone"
POCONO FM.
Mount Carbon Mbr
940'
Beckville Mbr
225'
Spechty Kopf Mbr
435'
CATSKILL FM. 6550-8600'
Duncannon Mbr.
1900-3000'
Sherman Creek Mbr
1500-2700'
Irish Valley Mbr
2500-3150'
upper
2200'
lower
900'
Kingsmill Ss
TRIMMERS ROCK - HARRELL FMS., undivided
2200-2700'
MAHANTANGO FM

Figure 36. Upper Devonian and Lower Mississippian stratigraphic terminology in central Pennsylvania.

stones are similar to the siltstones except for grain size. The bedding is thin to very thin and planar. Individual beds ordinarily maintain a constant thickness over the entire length of an outcrop. Graded bedding is characteristic of the Trimmers Rock siltstones, which fine upward from coarse silt (or fine sand) to very fine silt (or very fine sand). Flute casts, groove casts, load casts, ball-and-pillow structures, slump structures, burrows, and ripple marks are also common (Figure 39). The Trimmers Rock is locally fossiliferous, particularly in the upper sandy beds, having marine brachiopods, pelecypods, crinoid columnals, and lenses of fossil debris (Willard, 1932).

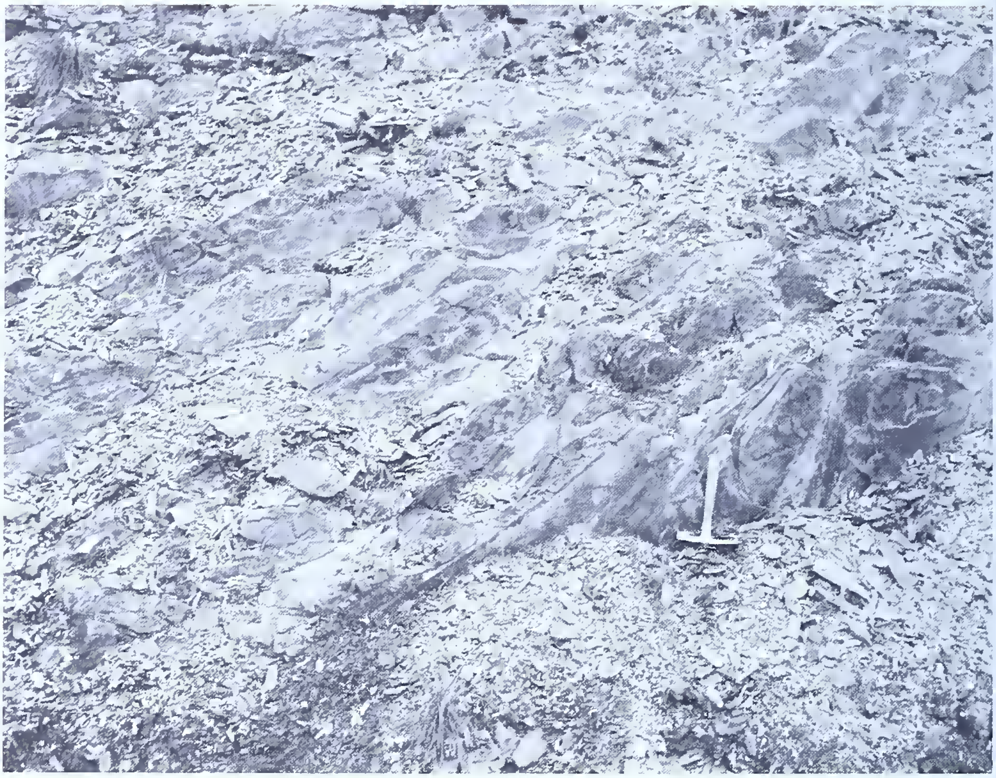


Figure 37. Harrell Formation outcrop at the junction of Pa. Routes 17 and 235 in Liverpool Township, Perry County. The long, straight groove cast in the foreground is on the under surface of a bed. Bedding is nearly vertical at this location.

Outcrop Area and Thickness

The Trimmers Rock-Harrell units are exposed in Quaker Valley synclinorium in two belts, one of which extends northeastward from East Salem towards Shadle, and the other eastward from East Salem to Oriental. Another large area underlain by the Trimmers Rock-Harrell is in Perry Valley, in the south limb of the Tuscarora Mountain anticlinorium.

The Trimmers Rock-Harrell usually develops a distinctive topographic expression in a homoclinal structure. Because of its stratigraphic position between the less resistant shales of the Sherman Ridge Member and the more resistant sandstones in the lower part of the overlying Catskill Formation, the Trimmers Rock generally occupies scarp slopes on ridges capped by the Catskill. The Harrell occasionally crops out near the foot of these slopes. The distinctive topographic expression of the Trimmers Rock-Harrell is a high-density trellis drainage characterized by steep, V-shaped valley walls and flat ridges between valleys.

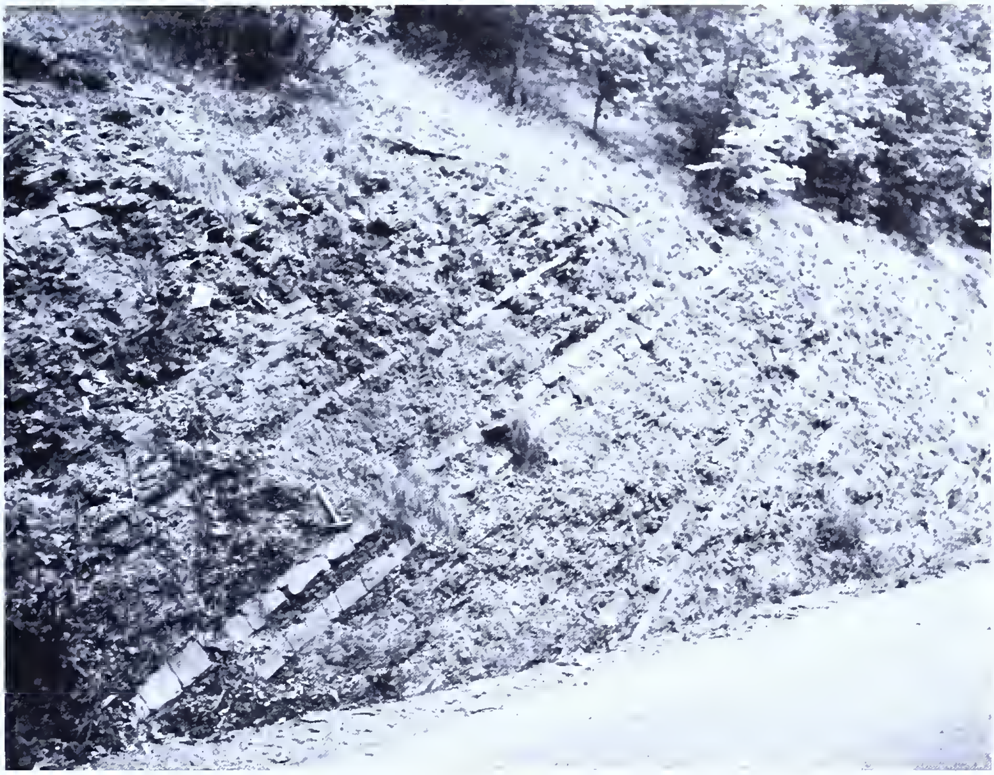


Figure 38. Trimmers Rock Formation exposure 0.5 mile north of Maze, Delaware Township, Juniata County. These beds are light-olive-gray shale, siltstone, and very fine grained sandstone near the base of the Trimmers Rock.

The Harrell Formation is approximately 200 feet (60 m) thick. The Trimmers Rock Formation is estimated at 2000 to 2500 feet (600 to 760 m) thick in the Millerstown quadrangle. Thicknesses of the Trimmers Rock-Harrell and correlative rock intervals from surrounding areas are compiled in Table 19. Isopach maps have been published by McIver (1961), Frakes (1967), and Wood and others (1969).

Formation Boundaries

The nature of the basal contact of the Harrell Formation with the Mahantango is unknown because of the lack of exposure within the Millerstown quadrangle. Elsewhere, the contact is fairly sharp, being "transitional only through a few feet" (Conlin and Hoskins, 1962). The contact of the Harrell with the overlying Trimmers Rock appears to be gradational. South of the quadrangle, this gradational zone consists of interbedded shale and "thin, blocky, medium-gray, fine-grained sandstone beds that increase in number and thickness upward" (Dyson, 1967).

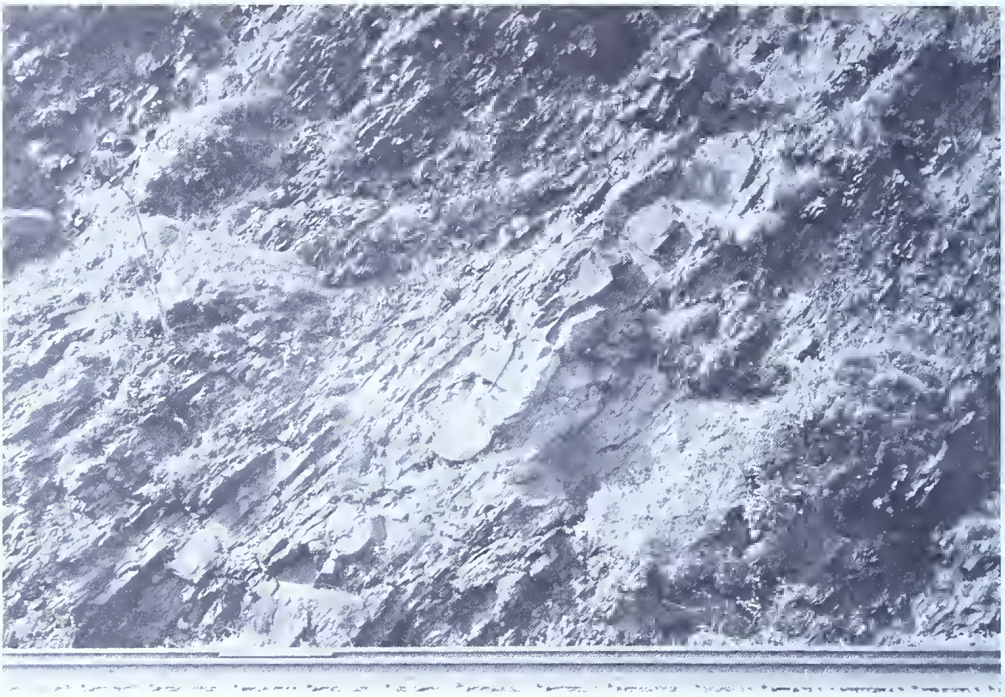


Figure 39. Trimmers Rock Formation exposure along west side of the Juniata River on the east end of Hominy Ridge, 1 mile south of Millerstown, Perry County. Units shown here are light-olive-gray siltstone, shale, and very fine grained sandstone. Prominent load-cast structures are visible near the center of the photograph.

The top of the Trimmers Rock is placed at the base of a sandstone bed that constitutes the base of the lowest upward-fining cycle which culminates in grayish-red silty claystone characteristic of the Catskill Formation. The best exposure of this contact is in a roadcut on the east side of the Juniata River just south of the Newport bridge. Although regionally the Trimmers Rock and Catskill Formations are intertonguing (McIver, 1961; Wood and others, 1969), this contact seems to occupy the same position throughout the Millerstown quadrangle.

Wheeler (1963) postulates a major unconformity between the "Chemung" (Trimmers Rock Formation) and the overlying Catskill Formation extending over much of eastern and central North America (the Acadian discontinuity). No evidence for such a major break in deposition was noted in the Millerstown quadrangle.

Age

In that the underlying Tully interval of the Sherman Ridge Member of the Mahantango Formation is of uppermost Middle Devonian age,

Table 19. *Thickness Values for the Trimmers Rock and Harrell Formations in the Vicinity of the Millerstown Quadrangle*

Locality	Quadrangle*	County	Thickness		Total thickness Harrell and Trimmers Rock	Source
			Harrell Fm.	Trimmers Rock Fm.		
Eschol	Loysville	Perry	**200–300′ (61–91 m)		2,650–2,750′ (808–838 m)	Miller, 1961
Half Falls Mountain	New Bloomfield	Perry	200′ (61 m)		2,300′ (701 m)	Dyson, 1963
Marysville and southeast Perry Co.	Harrisburg	Perry			1,785′ (544 m)	Willard and others, 1939
Susquehanna Gap	Harrisburg	Perry	190′ (58 m)			Dyson, 1967
Millerstown	Millerstown 7½′	Perry		1600′ (488 m)		Frakes, 1967
Liverpool	Millersburg 7½′	Perry		1,690′ (515 m)		Frakes, 1967
Washington	Lykens	Northumberland			2,200′ (671 m)	Wood and others, 1969
	Millerstown	Juniata, Perry	200′ (61 m)	2,000–2,500′ (610–762 m)	2,200–2,700′ (671–823 m)	this report

* Refers to 15-minute quadrangle unless otherwise stated.
** Thickness of the Harrell at Eschol includes the Burket Member of the Rush Formation.

the Harrell Formation and Trimmers Rock Formation are Upper Devonian in age (Finger Lakes Stage, Senecan Series) (Oliver and others, 1969). The Trimmers Rock is a time-transgressive unit, representing sedimentation in an environment which migrated westward through time as basin filling proceeded. Hence, similar lithologies are progressively younger to the west and southwest, and the above age assignment is valid only in the lower Juniata and Susquehanna Valley region.

Sedimentation

The barren shales of the Harrell suggest a deep-water environment. The long groove cast seen in the Harrell in Liverpool Township was formed by an object (probably a shell or pebble) which was dragged, drifted, or slid across the muddy bottom, and is diagnostic of current action. The Harrell, then, may represent a deepening of the basin and a change from the shallow conditions extant during Mahantango sedimentation to the deeper, turbidite sedimentation of the Trimmers Rock. Sedimentary structures in the Trimmers Rock Formation indicate that it is essentially a turbidite flysch deposit, i.e., a deep-water marine clastic sediment transported and deposited in large part by density currents (turbidity currents) which flowed down the paleoslope and across the sea floor. The principal indicator of turbidite sedimentation is the presence of graded bedding in thin and very thin units which persist laterally over considerable distances (Wells, 1961; Bouma, 1962). The prevalent flute and groove casts, slump structures, ball-and-pillow structures, and load casts are also characteristic of turbidite deposition.

The greater prominence of graded beds in the lower part of the Trimmers Rock and the increasing occurrence of medium-bedded sandstones with sharp upper and lower contacts in the upper part suggest a decrease in depth of water as sedimentation progressed. The more prevalent fossil material (showing less evidence of transport and abrasion) in the upper part supports this conclusion.

McIver (1961, 1970) and Frakes (1967) both concluded that the Trimmers Rock beds were deposited by bottom currents flowing westward from a source area of sedimentary and low-rank metamorphic rocks that lay to the east or southeast. R. G. Walker (1967) established criteria for differentiating proximal turbidite deposits (those deposited at the foot of the basin slope) from distal turbidite deposits (which have been transported some distance across the basin floor). Using these criteria, the Trimmers Rock is interpreted as a distal turbidite deposit in the lower portion of a basin. These turbidites become slightly more proximal toward the top, but never acquire the characteristics of a true proximal turbidite (i.e., thicker bedding, relatively coarser sand, and poorer internal size grading), perhaps because of an insufficient sand supply or a decrease in bottom currents. This change probably reflects the westward migration of the Catskill delta, of which the Trimmers Rock Formation is an offshore marine facies (McIver, 1961, 1970).

McIver also found a very uniform transport direction indicated in the Upper Devonian turbidite sandstones in central Pennsylvania and parts of adjacent states. He used directional sedimentary structures such as groove casts and flute casts, orientation of invertebrate fossils and plant fragments, and internal grain orientation. The average current direction, based on 2,400 readings at 297 exposures in the central Appalachians, is approximately due west, and is in close agreement with some 200 grain-orientation analyses that were made.

Catskill Formation

Name and Extent

The uppermost and by far the thickest formation in the Susquehanna Group is the Catskill Formation (Ponent Series of Rogers, 1858). The name Catskill originated in the Catskill Mountains of east-central New York (Mather, 1840) and has been applied since the 1880's to the sequence of predominantly red, nonmarine rocks (and the underlying transitional marine-nonmarine rocks) of Upper Devonian age in Pennsylvania (White, 1881, 1882; Claypole, 1885; d'Invilliers, 1891, among others; see also Chadwick, 1933 for the early history of the name Catskill). Although a lower "Chemung-Catskill transition" series was recognized (e.g., Claypole, 1885, p. 288) and specific units in the Catskill were named (Kings Mill sandstone, Dellville sandstone), the Catskill Formation in the lower Juniata and Susquehanna Valleys was not formally subdivided until recently (Arndt and others, 1962; Dyson, 1963, 1967).

Arndt and others (1962) divided the Catskill Formation into a lower marine and nonmarine, varicolored Irish Valley Member and an upper nonmarine, dominantly red Buddys Run Member. The type sections for both members are located near Shamokin in Northumberland County, 20 miles (32 km) northeast of the Millerstown quadrangle. Dyson (1963) used the same subdivisions at Newport, but farther to the south at Clarks Ferry (8 miles, 13 km, south of the Millerstown quadrangle), he replaced the Buddys Run Member with the Sherman Creek, Clark's Ferry, and Duncannon Members (Dyson, 1967). The Sherman Creek consists of 3500 feet (1067 m) of nonmarine red beds (sandstone, siltstone, and shale) and is lithologically similar to his Buddys Run Member at Newport. The Clark's Ferry is a coarser, predominantly gray and grayish-red sandstone. The Duncannon consists of interbedded red and nonred sandstones and grayish-red siltstones and shales. The Clark's Ferry Member is not present, and the Buddys Run Member, equivalent to the Duncannon and Sherman Creek, is not used in the Millerstown quadrangle. A comparison of Upper Devonian stratigraphic terminology used in the Millerstown and the adjacent quadrangles is shown in Figure 36.

The subdivision of the Catskill Formation in the Millerstown quadrangle is based on a distinct three-part symmetry in which a thick, medial interval of red siltstone and shale (Sherman Creek Member) is sandwiched between units that contain interbedded red and nonred sandstone, siltstone, and shale. The lower member, the Irish Valley, includes the marine-nonmarine transition beds at the base, and an overlying gray and grayish-red, upward-fining cyclic sequence. This usage of Irish Valley encompasses somewhat more than that of Dyson (1963), and includes the lowest 500 feet (150 m) of his Buddys Run Member (Figure 40).

Overlying the Irish Valley is the Sherman Creek Member, consisting of interbedded grayish-red siltstones and silty claystones, with a prominent gray sandstone interval near the middle.

The upper member is the Duncannon, comprising gray and grayish-red sandstones and grayish-red siltstone and shale, arranged in asymmetrical, upward-fining cycles that are, in general, thicker than those in the Irish Valley Member. Grayish-red siltstone and claystones predominate in the Duncannon, although a number of prominent thick gray sandstones occur toward the top of the member (Plate 6).

The Kings Mill Sandstone bed (Claypole, 1885) is a distinctive gray conglomeratic sandstone occurring near the base of the Irish Valley. It can be traced over much of the southern part of the Millerstown quadrangle, but is not readily discernible in the northern part.

The members of the Catskill Formation used in the Millerstown quadrangle are defined in terms of units in the Newport section in Figure 40.

The name Catskill has been carried from the Catskill Mountains in New York across Pennsylvania to the Susquehanna and Juniata River valleys. The Irish Valley has been used from the western anthracite region to the Juniata valley. The Sherman Creek Member can be traced for some distance beyond the borders of the Millerstown quadrangle; the Duncannon Member has been mapped in the Millerstown, Millersburg, and New Bloomfield quadrangles, and is recognized as far east as Monroe County (Sevon, in press) and as far northwest as the Lock Haven area (Taylor, in press). More regional correlations of the Catskill are given in Oliver and others (1969) and Shepps (1963).

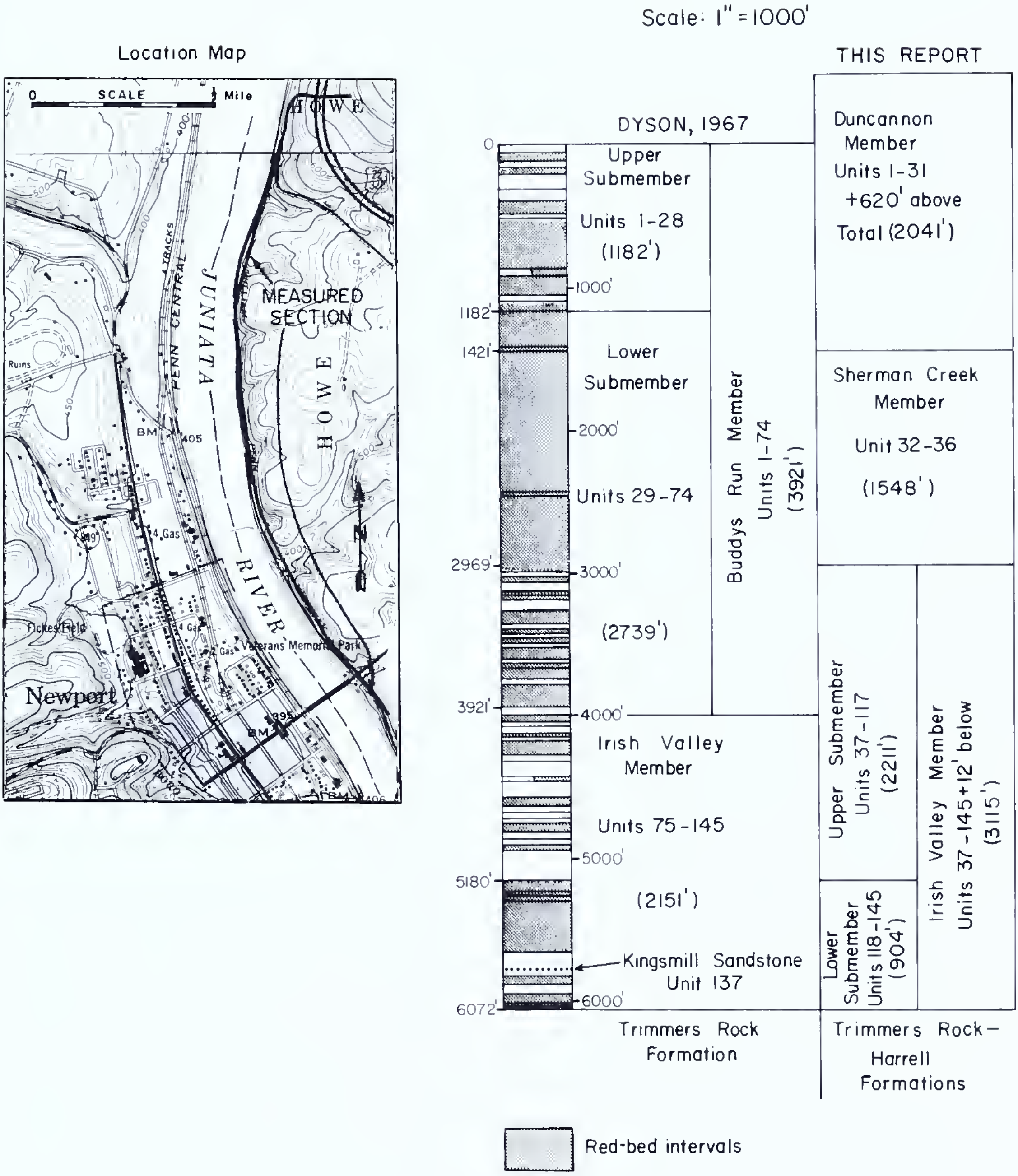


Figure 40. Newport Devonian section, exposed along the William Penn highway on the east side of the Juniata River opposite Newport, Pennsylvania, showing the subdivisions used by Dyson (1963) and those used in this report.

Character

The Catskill Formation consists of red and nonred clastic rocks that are divisible into three distinctive members in the Millerstown quadrangle.

The Irish Valley Member is a heterogeneous unit consisting of two contrasting, interbedded red and nonred lithologic assemblages: marine shales, siltstones, and sandstones; and nonmarine, asymmetric, upward-fining cycles.

The marine rocks are largely nonred (light olive gray, light gray or gray brown) and are predominantly siltstones (ranging from silty claystones to very fine sandstones). Bedding is generally thin to medium and planar, and individual siltstone and sandstone beds generally have sharp tops and bottoms. Some of the siltstones possess a well-developed size grading, similar to the turbidite beds in the underlying Trimmers Rock Formation. Marine fossils are common in these beds; some of the sandstone beds contain brachiopods and pelecypods. Thin lenses of brachiopod shell coquina occur sporadically, and a number of beds are burrowed.

These sequences of marine beds (5 feet to 50 feet, 1.5 to 15 m thick) are interbedded with nonmarine rocks of similar thickness. The nonmarine beds are generally organized into asymmetric upward-fining cycles, a sedimentological pattern that is characteristic of much of the Catskill Formation. These cycles ideally consist of four lithologic elements (see Table 20 and Figures 41 and 43). The base of the cycle is nonred sandstone (element A), overlain by grayish-red sandstones (element B), red siltstones (element C), and red silty claystones or shales (element D). Although not all of the cycles contain all four elements, the sequence of those elements present is always consistent with that of the complete cycle. Interrupted cycles (e.g., A-B-A-B-C-D) and nested subcycles (e.g., A-B-C-B-C-B-D) are common. These cyclic sequences range from 10 to 50 feet (3 to 15 m) in thickness in the Irish Valley.

The upward-fining cycles generally have an erosional base, with a concave-upward geometry. The upward decrease in grain size is usually gradational, from a basal medium- or fine-grained sandstone to a fine siltstone or silty claystone at the top. The sandstones are generally thick bedded to massive, and crossbedded in the lower few feet, becoming planar bedded above. The finer sediments are usually thin and medium bedded, although no regular upward decrease in bed thickness was observed. The advent of red coloration usually occurs at the approximate level of the change in grain size from very fine sand to coarse silt, although in many examples the nonred color persists well up into the finer sediments. The intensity of the red color noticeably increases in

Table 20. *Sedimentological Elements of the Fining-Upward Cycles in the Duncannon Member of the Catskill Formation*

The cycles in the upper part of the Irish Valley Member are similar, but are generally thinner, and ordinarily lack the conglomeratic zones and coal layers. See Figure 41 and Plate 6.

Element	Color	Lithology	Remarks
(upper) A	Grayish red (10R4/2); locally greenish gray (5GY6/1) in upper few inches.	Silty claystone and shale.	Generally medium bedded to massive. Nested subcycles common.
B	Grayish red (5R4/2)	Siltstone, argillaceous, very finely sandy in lower part.	Thin- to thick-bedded, crossbedded, with gradational base and fairly sharp, planar top. Ripple marks common. Clastic dikes occur in Duncannon Member.
C	Grayish red (5R4/2) to dark grayish red (5R3/2). Red color increases towards edges of channels.	Sandstone, very fine grained, silty, locally fine to medium grained at base. Occasional shale clasts.	Medium- and thick-bedded, crossbedded channel deposit; becomes planar bedded towards the centers of the channels.
(lower) D	Medium to light gray (N5 to N7) and light olive gray (5Y6/1).	Sandstone, very fine to medium-grained, local basal conglomerate. Angular shale clasts are common. Occasional carbonate nodules and bituminous coal lenses.	Occupies erosional channels, lower contact sharp and often grooved, medium-bedded to massive, crossbedding grades laterally and upward into parallel lamination.

the finer sediments toward the tops of the cycles. The upper few inches of the grayish-red silty claystone at the top of many cycles is commonly a greenish-gray color. This color change follows the bedding only generally, often having an irregular or patchy distribution.

Ripple marks and parting lineations are fairly common in the Irish Valley, particularly in the finer sand fractions. In the upper part, fossil plant material and pieces of petrified wood are found in the olive-gray sandstones. Small limestone concretions occur in the basal portion of some of the upward-fining cycles. These concretions are small (less than

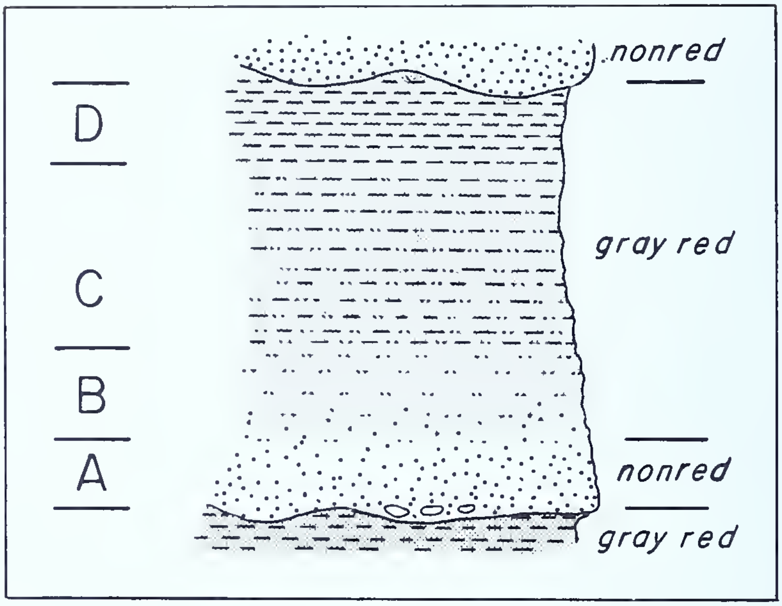


Figure 41. Idealized Duncannon Member fining-upward cycle, as seen in the exposures along U.S. Route 22-322 at Buffalo Mountain (Plate 6).

5 mm in diameter), well rounded, nodular, may have a concentric layering, and are sometimes partially replaced by pyrite. Nuclei, where they occur, are generally detrital fragments of calcilutite and microcrystalline or pelletal limestone.

The interbedding of the marine and nonmarine sequences occurs in the lower 892 feet (272 m) of the Irish Valley (units 118 through 145, Newport section, Dyson, 1963). This interval constitutes the transition between the marine deposition of the Trimmers Rock Formation and the fluvial deposition common to the Catskill. The change is gradual, with the number of upward-fining cycles increasing upwards (and with a complementary decrease in the number and thickness of the marine sequences). The upper part of the Irish Valley consists almost solely of the nonmarine cycles (units 37 through 117, Newport section, Dyson, 1963) and is 2211 feet (674 m) thick at Newport.

Although these two contrasting rock assemblages can be fairly well delineated in well-exposed sections (such as at Newport), their common contact cannot be mapped and thus both are included in the Irish Valley Member.

According to Walker and Harms (1971) there are between 20 and 25 marine-nonmarine alternations in the Irish Valley Member in the Susquehanna Valley area. Nine of these cycles were measured in the lower 900 feet (274 m) of the Newport section (Walker, 1971). Each of these cycles, which are termed "motifs," consists of a sharp, generally planar basal surface, overlain by gray and greenish-gray fossiliferous sandstone, siltstone, fissile shale, and mudstone in the marine phase, and red siltstone and mudstone in the upper, nonmarine phase. The sequence of rocks of the marine phase consists of a lower, bioturbated, fossiliferous sandstone containing bone fragments, phosphatic nodules, brachiopods, and crinoids, overlain by an olive-gray fissile shale. Above this are alternating beds of siltstone, mudstone, and fine-grained sandstones which are crossbedded, horizontally laminated, or ripple cross laminated. The upper, nonmarine phase is dominantly grayish-red siltstone and mudstone containing rootlets, desiccation cracks and tan calcareous nodules.

The Kings Mill sandstone bed is predominantly a gray, fine- and very fine grained, fossiliferous sandstone bed within the Irish Valley Member and is 15 to 20 feet (4.5 to 6 m) thick in the Newport area. Although the Kings Mill sandstone is generally well cemented with silica it is locally fairly porous and friable. Northwest of Newport, the sandstone contains a conglomerate which occurs in lenses up to three feet (1 m) thick. The conglomerate is approximately 90 percent well-rounded quartz pebbles, which have an average diameter of 1/2 inch (1.3 cm), a maximum size of 1 1/2 inches (3.8 cm), and a distinctive tabular shape (Figure 42). Other constituents include gray shale pebbles, jasper, crystalline igneous rock fragments, and rare well-rounded crinoidal limestone pebbles. The Kings Mill Sandstone can be traced westward around the hinge of the Buffalo-Berry synclinorium and thence eastward to the Juniata River where it apparently thins; it is not recognized east of the river. However, further eastward in Perry Valley and also in the Quaker Valley synclinorium the Irish Valley contains conglomeratic sandstone beds at approximately the same stratigraphic position as the Kings Mill sandstone.

The conglomeratic sandstones east of the Juniata River (extending from Wildcat Run in Perry Valley eastward to the Susquehanna River) are light olive gray to gray brown, very fine to coarse grained, fossiliferous (large spirifer brachiopods), and medium bedded. The beds and lenses of conglomerate (maximum thickness of 3 feet, 1 m) in this sandstone are composed largely of white, tabular quartz pebbles similar to those in the Kings Mill, and have an average maximum size of 1/4 to 3/4 inch (.6 to 1.9 cm).

In the Quaker Valley synclinorium, a conglomerate approximately 1 to 6 feet (0.3 to 2 m) thick occurs just above the main body of the basal sandstone. The quartz pebbles in this conglomerate are equant rather than tabular, and range up to one inch (2.5 cm) in size. The matrix is generally medium-gray (occasionally grayish-red), fine- to medium-grained sandstone.

The Sherman Creek Member, which overlies the Irish Valley in this area, is distinctive in the large proportion of red beds it contains, the absence of well-developed fining-upward cycles, and the general lack of sediment coarser than very fine sand. The Sherman Creek is primarily grayish-red to reddish-gray siltstone and silty claystone with minor intervals of very fine grained, crossbedded sandstone. Most of the unit is medium to thick bedded and generally the contacts between beds of contrasting grain size are slightly irregular and sharp rather than gradational. The alternation of siltstones and silty claystone beds gives the Sherman Creek Member a distinctive symmetrical cyclicity, which contrasts with the asymmetrical cycles in the Irish Valley and Duncannon Members.

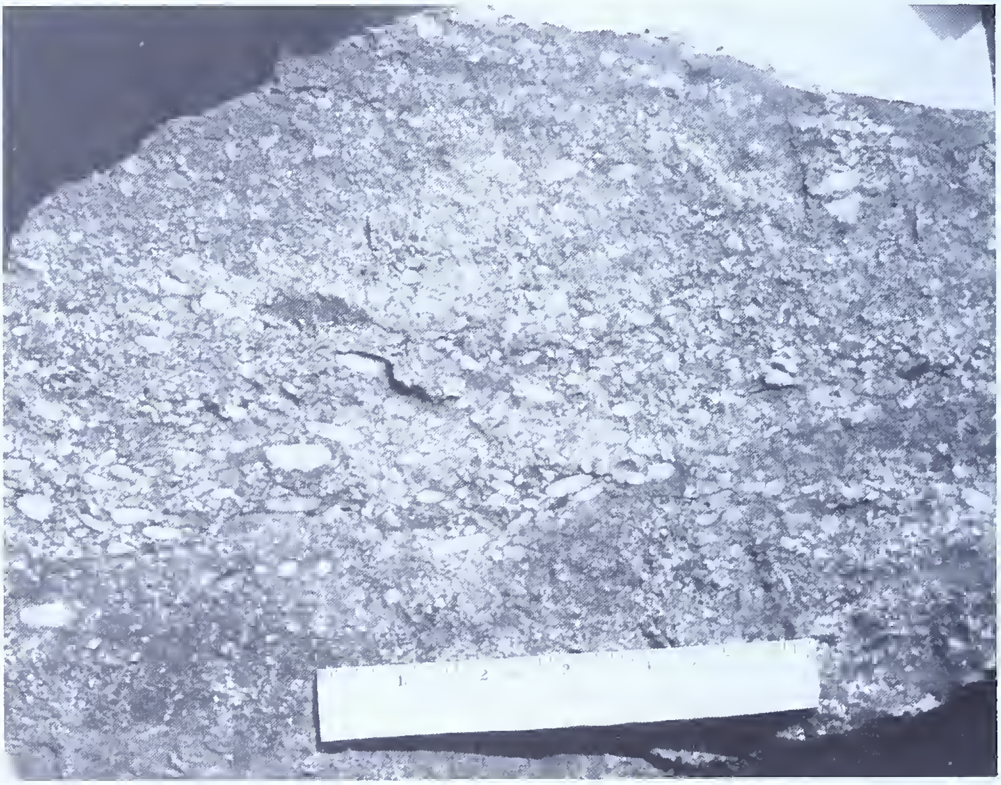


Figure 42. Block of tabular quartz-pebble conglomerate of the Kings Mill sandstone, from an exposure on the south side of Hominy Ridge in Juniata Township, Perry County. Clasts are principally discoidal- or tabular-shaped quartz and quartzite, but limestone pebbles are also present. Scale in inches.

The asymmetric, upward-fining cycles that are common in the Irish Valley dominate the upper member of the Catskill Formation, the *Duncannon Member*. As in the Irish Valley, the cycles contain up to four elements, from nonred sandstone (element A) at the base to the grayish-red silty claystone and shale (element D) at the top (see Table 20 and Figures 41, 43, and 44). There are also significant differences between the Irish Valley and Duncannon cycles. The cycles in the Duncannon are generally much thicker (30 to 150 feet, 9 to 45 m), better organized, and individual elements within the cycles are also thicker.

The sandstones are generally micaceous, argillaceous, poorly sorted, and slightly siliceous, tend to be conglomeratic toward the base, and occasionally contain petrified wood and plant fragments. These sand-

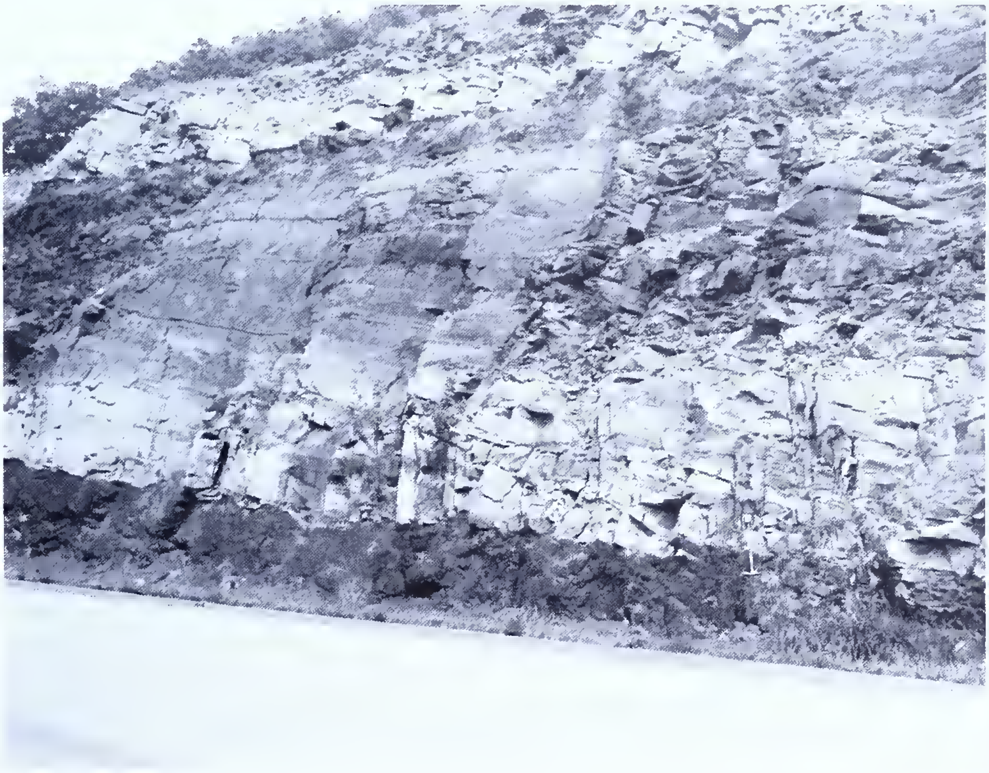


Figure 43. Fining-upward cycles in the Duncannon Member exposed along the southbound lane of U.S. Route 22-322 at Buffalo Mountain. Note the sharp contact at the base of the cycle and the distinct zonation within the cycle. Compare with Figure 41. Structure in foreground is a low-angle reverse fault dipping south, toward the axis of Buffalo-Berry synclinorium. Displacement is less than 1 meter.

stones often occupy channels eroded into the shale in the top of the underlying cycle, and occasionally steep-walled channels, produced by laterally cutting currents, are exposed. The color change from nonred to red tends to occur at the top of the sandstone interval. The combined effect of clay content and silica cement is to reduce the porosity and permeability, except in a few thin zones in the lower parts of the cycles where a poor to fair porosity was noted.

The conglomeratic lenses contain well-rounded pebbles of quartz, quartzite, siltstone, carbonate concretions, and angular shale fragments. The pebbles and concretions average 1/4 to 3/4 inch (.6 to 1.9 cm) in diameter, with a maximum of three inches (7.5 cm) (Figures 44 and 45). Thin laminae and lenses of bituminous coal (up to 1/4 inch, .6 cm thick) occur in the nonred sandstone beds of some cycles.

Only the lowest 1421 feet (433 m) of the Duncannon Member is exposed (intermittently) in the Newport section (units 1 through 31, Dyson,

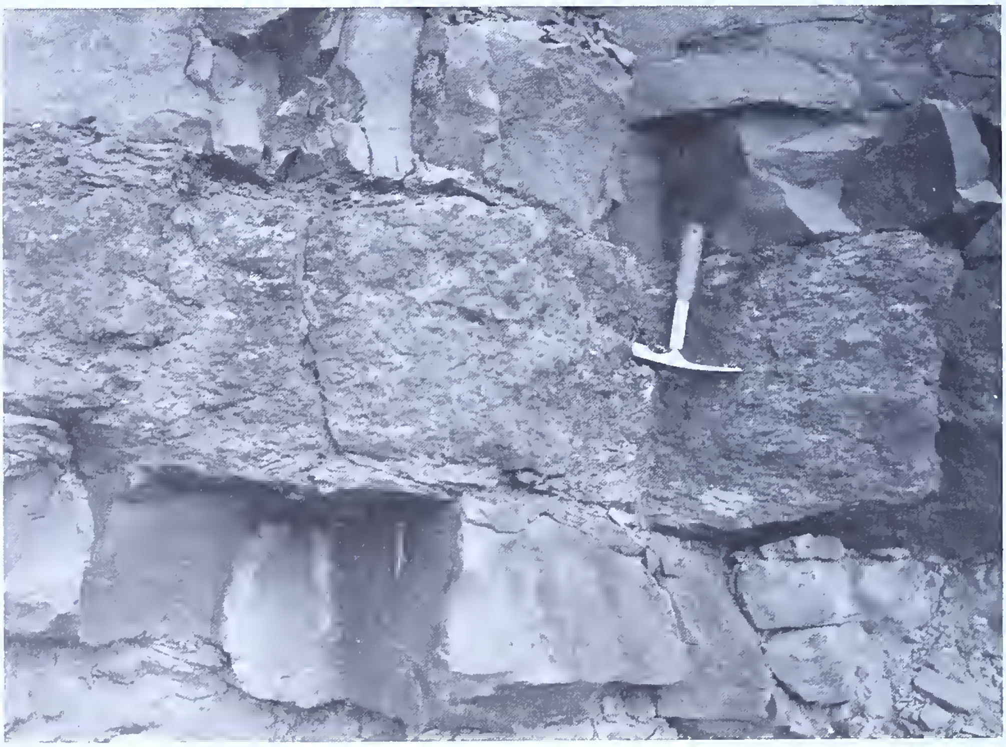


Figure 44. Conglomerate lens filling an erosional scour at the base of a cycle along the southbound lane of U.S. Route 22-322 at Buffalo Mountain. Clasts include shale fragments, coal chips, and siltstone and claystone pebbles which are generally ¼ to 1 inch in length, with a maximum observed length of 3 inches. Duncannon Member, Catskill Formation.

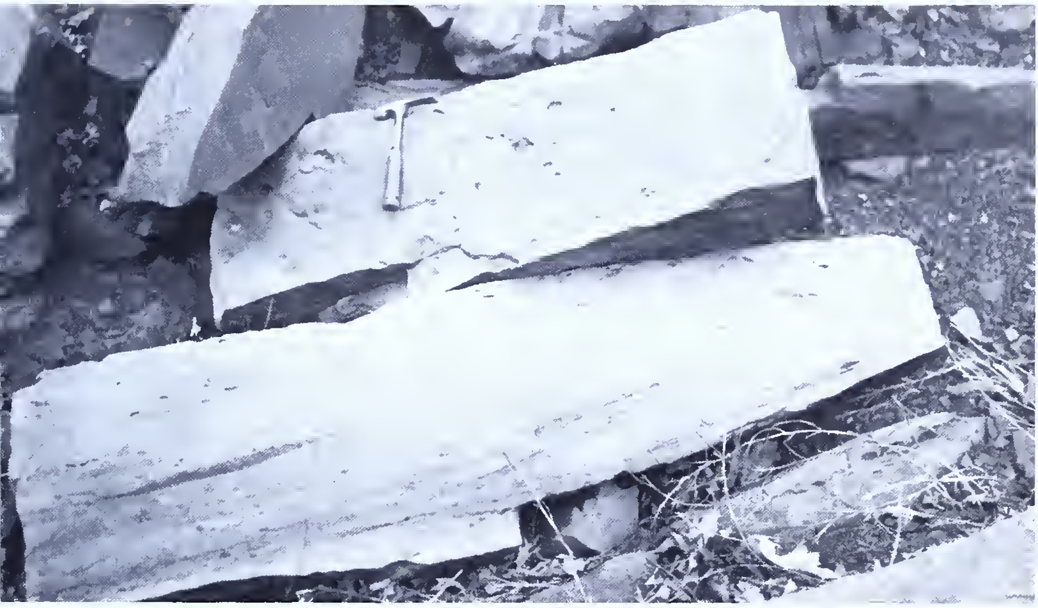


Figure 45. Conglomeratic sandstone in the base of a fluvial cycle in the Duncannon Member, Catskill Formation. Conglomerate consists of subrounded quartz pebbles and flattened clay pebbles, in a matrix of grayish-red, fine- to medium-grained sandstone. Pebbles are smaller than two inches in diameter. Block pictured here is right side up, and the talus block above shows a bedding-plane view of this lithology.

1963). The best exposure of the medial Duncannon is the recent roadcut on U.S. Route 22-322 at the hinge of the Buffalo-Berry synclinorium, which exhibits 312 feet (95 m) of vertical section, and 1/2 mile (.8 km) of lateral extent (Figures 43, 46, and Plate 6). Several complete fluvial cycles are exposed, ranging in thickness from 12 to 65 feet (4 to 20 m), a typical example of which is illustrated in Figure 43. A typical complete cycle, comprising elements A through D, is illustrated in Figure 43.

A number of clastic dikes (Wells, 1969) occur in the siltstones of at least one of the cycles in the Buffalo Mountain West section. These dikes are composed of dark- to light-grayish-red and greenish-gray, medium to coarse silt which locally grades into very fine grained sandstone. The dike material is argillaceous, micaceous, slightly hematitic, poorly sorted, and has little porosity or permeability. The host rock is a fine-grained, argillaceous siltstone, which is grayish red to dark grayish red. The dikes penetrate downward into the host rock from an overlying bed of sandy siltstone usually two to three inches thick, of the same color and lithology as the dikes themselves. These beds are minor interruptions of the fining-upward pattern, and are of limited lateral extent. The dikes are

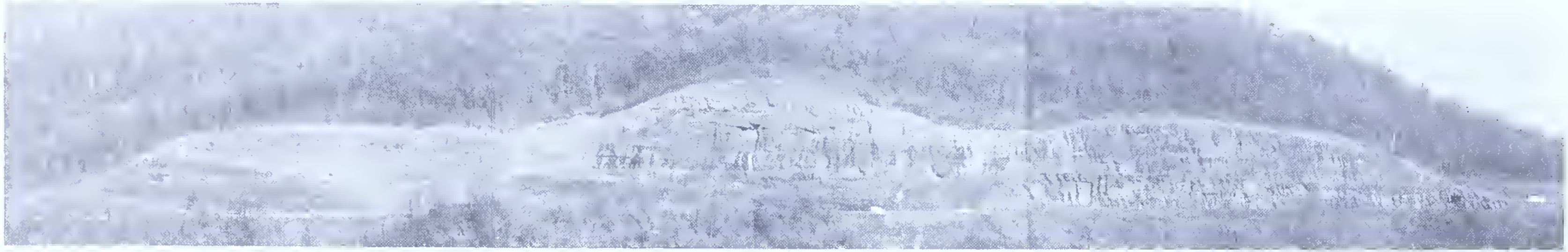


Figure 46. Exposure of Duncannon Member of the Catskill Formation on the west end of Buffalo Mountain in Howe and Greenwood Townships, Perry County. The Juniata River crosses the picture in the foreground; the upper and lower roadcuts on the mountain are the northbound and southbound lanes of U.S. Route 22-322. View is eastward, down the axis of the Buffalo-Berry syncline. Length of the exposure in this view is about 0.5 mile.

connected to the overlying beds and apparently formed from the same sediment. Angular fragments of the host rock sometimes occur in the upper parts of the dikes, and in the associated overlying beds (Figure 47, Plate 6).

The geometric form of these dikes is usually that of a slightly tapering subvertical wedge, and the dike walls are sharp. The dikes may be straight, slightly irregular, or have a zig-zag cross section. Six of these dikes were measured in detail. They range in height from four to twelve inches, and taper from a width of between 3/8 and one inch at the top to 1/2 to 1/16 inch or less at the base. The four dikes on which a strike could be determined trend from 115° to 150°, and dip from 50° southwest, through vertical, to 67° northeast. The dikes are restricted to a lateral distance of 35 feet at two stratigraphic levels three feet apart.

The uppermost part of the Duncannon occurs on the upper scarp slope of the ridges underlain by the Pocono Formation and is thus usually completely covered by scree. However, the roadcut along U.S. Route 11-15 on the west bank of the Susquehanna River at Berry Mountain (3/4 mile, 1.2 km, east of the southeast corner of the Millerstown quadrangle) exhibits more than 200 feet (61 m) of similar asymmetric, upward-fining cycles in the uppermost part of the Duncannon.

Outcrop Area and Thickness

The Catskill is the thickest formation exposed in the Millerstown quadrangle, and correspondingly underlies a greater land area than any

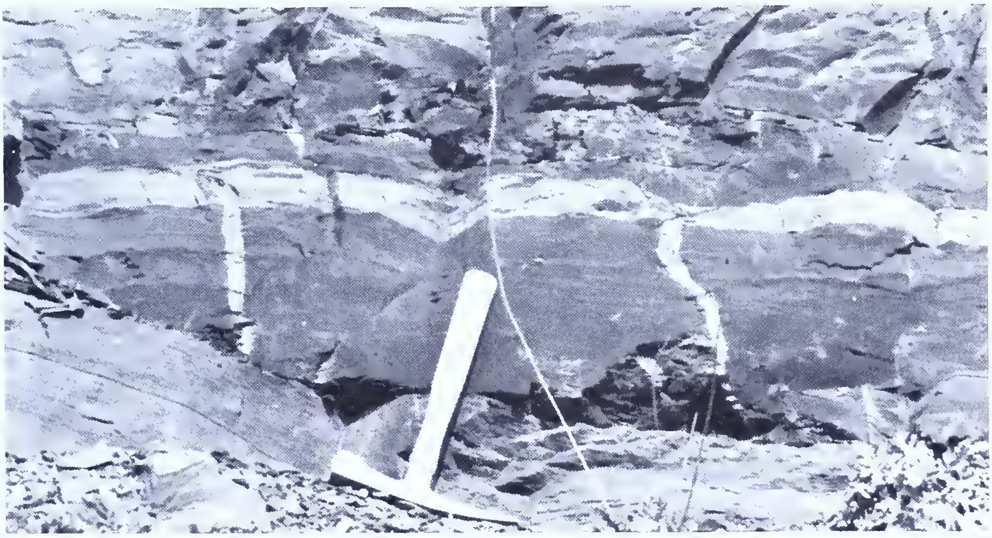


Figure 47. Clastic dikes in the Duncannon Member. Part C of a cycle exposed in the middle of three outcrops on the southbound lane of U.S. Route 22-322 at Buffalo Mountain.

other stratigraphic unit. There are two broad bands of Catskill outcrop here, both of which occupy prominent synclinal structures. The northern outcrop occupies the hinge of Quaker Valley synclinorium, extending from near East Salem northeastward to the east quadrangle boundary, and consists of only the Irish Valley Member. The southern outcrop belt includes all the members of the Catskill, and extends from the southwestern part of the quadrangle northeastward through Perry Valley to the eastern border. The Catskill Formation is also present south of Berry Mountain in Bucks Valley.

The Catskill Formation is estimated to be between 6550 and 8600 feet (1996 to 2621 m) thick in the Millerstown quadrangle.

Dyson (1963) published a partial measured section of the Catskill Formation at Newport, Pennsylvania, which occupies part of both the Millerstown and New Bloomfield quadrangles. This section covers all of the Catskill from the base to about the middle of the Duncannon Member, a thickness of 6072 feet (1850 m). New exposures above this section, and the mapping of the overlying Pocono Formation on Buffalo Mountain, permit the estimation of the total Catskill thickness at this locality. The interval from the top of Dyson's Newport section to the base of the Pocono Formation on Buffalo Mountain is approximately 620 feet (188 m) and the resulting total thickness for the Catskill Formation is 6704 feet (2043 m).

Ayrton's (1963) isopach map for the Upper Devonian shows a thickness of about 8000 feet (2438 m) in the Millerstown vicinity. Allowing for 2250 feet (686 m) of Trimmers Rock Formation, the remaining 5759 feet (1755 m) of Catskill shown by Ayrton is considerably less than the field relations seem to indicate.

Formation Boundaries

The base of the Catskill Formation is placed at the base of the lowest recognizable asymmetric, upward-fining cycle ("motif"), the sedimentologic pattern that is so characteristic of the Catskill. In the Newport section (Dyson, 1963), this horizon is 12 feet (4 m) below the base of the Catskill Formation as defined by Dyson (1963). Elsewhere in the Millerstown quadrangle, this contact cannot be as closely located because of poor exposures. However, the basal sandstones in the Catskill (including the Kings Mill) underlie a prominent ridge and the contact is usually located at or near the top of the scarp slope of this ridge.

The top of the Irish Valley Member is a mappable gray sandstone (unit 37, Newport section, Dyson, 1963).

The base of the Duncannon Member is placed at the lowest mappable, nonred sandstone above the medial gray sandstone of the Sherman Creek

Member. However, because the lowest Duncannon sandstone beds do not persist across the entire quadrangle, this contact does not maintain a constant stratigraphic position. From the southwestern part of the quadrangle northeastward into Perry Valley, the lowest mappable sandstone is approximately 1650 feet (503 m) above the medial gray sandstone in the Sherman Creek Member. South of Reward (Perry Valley), three separate gray sandstones, which mark the base of asymmetrical fining-upward cycles, occur in the Sherman Creek Member. To the west, these units become finer grained, thinner, and gradually change to a grayish-red color and become indistinct. To the east, these sandstones become thicker, coarser grained, and more prominent. The arbitrary shift of the base of the Duncannon is based on the presence of these nonred sandstones. In the eastern part of Perry Valley the base of the Duncannon is approximately 375 feet (114 m) above the Sherman Creek medial gray sandstone. The Sherman Creek and Duncannon Members intertongue in this area, as shown by an interval of strata of Sherman Creek facies overlying these discontinuous lower Duncannon sandstones.

Although not exposed in the Millerstown quadrangle, the contact of the Catskill Formation with the Spechty Kopf Member of the Pocono Formation can be seen at the Berry Mountain roadcut (3/4 mile, 1.2 km, east of the quadrangle) where it is conformable and rather abrupt. The contact is placed at the top of the uppermost asymmetric, upward-fining cycle of gray sandstone and grayish-red shale. This occurs at the southern end of the roadcut bench along U.S. Route 11-15 on the west side of the Susquehanna River, where the highest Catskill cycle is approximately 50 feet (15 m) thick.

All of the contacts within the Catskill are apparently conformable. Numerous erosion surfaces occur within the formation (at the base of the asymmetric cycles) but these appear to be of local extent. Regional studies summarized by Hoskins (1963) indicate that the Catskill members are not only conformable, but also interfinger to some degree, so that each is mutually correlative, in part, with the underlying or overlying member.

Age

The Catskill Formation is Upper Devonian in age in the Millerstown quadrangle, and correlates with the Cohocton Stage of the Senecan Series, and the Cassadaga and Bradford Stages of the Chautauqua Series. These correlations result largely from the occurrence of marine brachiopods and pelecypods of Senecan age in the Irish Valley Member and the identification of both Upper Devonian and Lower Mississippian plant fossils in the overlying Spechty Kopf Member of the Pocono Formation (Trexler and others, 1962).

Sedimentation

The Catskill Formation is interpreted to be the product of deposition in alternating marine and nonmarine environments (in the transitional interval of the Irish Valley Member) and in nonmarine environments (above the transitional beds).

The transition zone is marked by a cyclic alternation of marine and nonmarine beds. According to Walker and Harms (1970), these motifs represent marine transgressions in which no significant amounts of shoreline sand were deposited. Sedimentation proceeded along a broad, muddy coastline where there was a large amount of fine sediment being carried in suspension, and shoaling of the waves occurred far offshore.

Most of the Catskill Formation above the transitional beds in the Irish Valley Member was formed on an alluvial floodplain or coastal plain which was crossed by several rivers. The principal evidence for this interpretation is the occurrence of fossil land plants and coal-bearing beds, the presence of asymmetrical channels which are comparable to modern river channels, and the nature of the fining-upward cycles.

The cyclic alternation of coarse and fine sediments in the Catskill Formation is comparable to the sedimentation patterns in recent alluvial valleys, as described by Allen (1965a). The presence of a scoured horizon at the base of each cycle, followed by deposition of progressively finer sediment, is evidence of a regular decrease in available energy and fluid velocity. According to Allen and Friend (1968), the fining-upward cycles in the Catskill represent a combination of channel cutting, channel filling and, in the siltstone and claystone parts of the cycles, deposition in natural levees, floodplains, and flood basins. The cycles are repeated through the processes of avulsion (the cutting off of meander necks by streams) and lateral migration of the channels on the floodplain, during a period of fairly continuous subsidence. An alternative explanation for the repetition of these cycles is a periodic base-level change of tectonic origin, through differential uplift in the source area and/or subsidence in the basin of deposition, as postulated by Fletcher (1967).

The floodplain environment represented by the sediments of the Catskill Formation was located on the upper portion (topset beds) of a large delta (Barrell, 1913). Paleocurrent studies by McIver (1960), in an analysis of 900 crossbedding dip direction readings in the Catskill red beds, calculated a mean-current azimuth of 292°. The source region apparently lay to the east in the vicinity of the present Atlantic coastline. This familiar pattern of an eastern source area and westward paleocurrent directions is somewhat similar to that which prevailed during the deposition of several earlier Paleozoic formations, including the Juniata, Tuscarora, and Trimmers Rock Formations.

The lowest prominent sandstone in the Catskill (e.g., the Kings Mill Sandstone and its correlative beds) is interpreted as a delta-front deposit. This sandstone interval marks the change from deep water, prodelta sedimentation, represented by the Trimmers Rock Formation, to the shallow water marine and nonmarine sediments of the Catskill Formation. Glaeser (1970) reported a similar, although thicker, delta-front sandstone in the same relative stratigraphic position across northeastern Pennsylvania.

The red color of the Catskill (concentrated primarily in the silt- and clay-size sediment) is due to the presence of finely divided hematite, which resulted from oxidation of limonitic sediment. Studies of the clay minerals by Friend (1966) and Van Houten (1968), and of the petrography (Meyer, 1963) indicate that the red and nonred sediments at any given Catskill locality have identical source materials. The red beds are also thought to have climatic significance, and a comparison with modern nonmarine red sediments suggests deposition under humid tropical conditions (T. R. Walker, 1967, 1974). Dunbar and Rodgers (1957) noted that there is usually very little difference in the percentage of iron in the red shales and gray sandstones, but that the iron is ferrous in the sandstones. This implies that oxidizing conditions prevailed in the finer sediments either during deposition or after burial.

The differentiation of fine and coarse sediments into red and nonred strata is apparently the result of both primary and diagenetic conditions. The absence of red color in the coarser fraction may reflect reducing conditions in the local depositional environment of the sandstones, caused by the presence of organic material carried in the main stream channels. The finer, red sediments are interpreted as mainly overbank alluvial deposits, which accumulated on the floodplain where oxidizing conditions permitted the red color to develop. The observed direct correlation between grain size, color, and permeability suggests that the circulation of slightly acidic ground water in the sandstones permitted reducing conditions to be established, so that any red color which had formed was removed. The secondary alteration of some of the shales and claystones from red to nonred color is indicated by irregular areas of greenish-gray discoloration at the very top of many of the cycles. This distribution suggests that these uppermost layers were affected by the reducing conditions in ground water circulating through the overlying sandstones.

The presence of carbonate fragments and nodules in alluvial sequences has been reported from the Lower Old Red Sandstone of England by Allen (1965b) and in the Devonian of Spitsbergen by Friend and Moody-Stuart (1970). The carbonates in the Catskill probably originated as fresh-water limestones or caliche deposits. Some of the limestone concretions and nodules in the Duncannon Member apparently formed through direct precipitation, perhaps on nuclei of detrital carbonate grains, similar to those described by Bathurst (1958).

The clastic dikes observed in the Duncannon Member are interpreted as part of the overbank alluvial material which was deposited in small fissures in floodplain or flood-basin deposits. These fissures or crevasses probably originated through hillside creep or slumping of semiconsolidated mud toward local depressions or undercut banks. The sediment comprising the dikes and the overlying associated siltstone lenses may be part of a crevasse-splay deposit which spread out over the floodplain through breaks in natural levees. Such an origin is suggested by the coarser grain size of the sediment, the lobate cross section of the overlying siltstone beds, and the occurrence of the siltstones beyond the edges of channels. The small number of dikes present here is a reflection of the fact that their formation first required the opening up of cracks or small crevasses into which the sediment could settle. These openings developed only when a certain fortuitous combination of conditions of sediment character and downslope movement occurred, which was probably a rare event.

The Catskill Formation represents the initiation of a second phase of molasse sedimentation in the Appalachian geosyncline. The Catskill and the overlying Pocono Formations together form what has been called the Late Paleozoic Molasse (Potter and Pettijohn, 1963). In gross aspects, the Catskill and Pocono repeat an earlier phase of sedimentation, the Midpaleozoic or Taconic Molasse, which is represented by the Ordovician Juniata and Silurian Tuscarora Formations. In both instances, the sediments form an asymmetrical wedge which is elongate parallel to tectonic strike, paleocurrent directions are towards the northwest, graywacke and subgraywacke sandstones and red silts and claystones are dominant in the initial periods of sedimentation, the section becomes thinner and eventually grades into marine sediments down the paleoslope, and subsidence was fairly rapid near the eastern margin of the basin.

DEVONIAN AND MISSISSIPPIAN SYSTEMS, UNDIVIDED

The Mississippian rocks (the youngest rocks present in this quadrangle) include the gray sandstone and conglomerate of the Pocono Formation, and the predominantly red shale, siltstone, and sandstone in the Mauch Chunk Formation. The lower member of the Pocono Formation, the Spechty Kopf, is thought to be both Mississippian and Devonian in age. Approximately 3600 feet (1100 m) of Mississippian rocks is exposed in this quadrangle, but this includes only a portion of the entire sequence of Mississippian strata that occur in the Valley and Ridge province.

Pocono Formation

Name and Extent

The name Pocono, proposed by Platt and Platt (1877), was applied to the white and gray sandstones and conglomerates overlying the Catskill Formation, replacing the name Vespertine, No. X (Rogers, 1858). No type section was presented, although the exposures along the Lehigh River were apparently considered most typical of unit No. X and have been recommended as the type section by Sevon (1969a).

In central Pennsylvania, the Pocono was divided into two members, the Beckville and Mount Carbon Members. An underlying third unit, the Spechty Kopf, was considered to be a member of the Catskill Formation (Trexler and others, 1962). However, Dyson (1967) felt that the Spechty Kopf possessed a greater similarity to the overlying units than to the Catskill and reassigned the Spechty Kopf to the Pocono. The authors concur with Dyson and have adopted this three-fold division of the Pocono Formation for the Millerstown quadrangle.

The Pocono Formation persists as a mappable rock unit from northeastern Pennsylvania westward into Ohio and southwest as far as western Virginia. The individual members mapped in the quadrangle have not been traced beyond central Pennsylvania.

Character

The Pocono Formation is a coarse clastic unit consisting primarily of medium-grained sandstones with interbedded conglomeratic sandstone, conglomerate, and thin shale and siltstone beds. The sandstones (and the matrix of the conglomeratic sandstones) are generally gray, gray brown, or buff, medium to very thick bedded and crossbedded; the sand grains are very fine to very coarse, and subangular. The sandstones are poorly sorted, siliceous, and micaceous, slightly porous, locally argillaceous, and hematitic or pyritic. The conglomerates occur as lenses or beds containing subangular white quartz pebbles (.25 to .75 inch, 0.6 to 1.9 cm in diameter) and some chert, rock fragments, and shale pebbles. Occasional thin, reddish-gray and dark-gray carbonaceous silty shale beds occur in the Spechty Kopf Member. Three thin (1 inch, 2.5 cm thick) coal seams are reported in the Pocono Formation (Beckville Member) on Berry Mountain by Claypole (1885, p. 154). Although a drift was run into at the end of the mountain at the Susquehanna River, no commercial quantity of coal was found.

The Beckville and Mount Carbon Members are very similar. Both are conglomeratic at the base and fine upward to medium-grained sandstones. The Spechty Kopf has a prominent conglomerate interval near the middle and a less well developed conglomerate at or near the base. The lowest part of the Spechty Kopf consists of interbedded sandstone and dark-gray argillaceous siltstone, a pattern grossly similar to the upward-fining cycles of the underlying Duncannon Member of the Catskill. This pattern is not evident in the rest of the Pocono.

Outcrop Area and Thickness

The Pocono Formation is a prominent ridge-forming unit which occupies the crests of Buffalo and Berry Mountains in the southeast quarter of the quadrangle. Outcrops of the Pocono are few in the mapped area, but excellent exposures can be seen along both sides of the Susquehanna, where the river has worn gaps in both of these mountains (Millersburg quadrangle, Figure 48).

The Pocono Formation is approximately 1600 feet (488 m) thick in the Millerstown quadrangle. Measurements of the Pocono and its members in this and adjacent quadrangles are tabulated in Table 21.

An isopach map of the Pocono Formation (Pelletier, 1958) shows a general westward and northward thinning from 1800 feet (549 m) near Harrisburg to less than 200 feet (61 m) in western New York and Ohio.

Formation Boundaries

Neither the upper nor lower contact of the Pocono Formation is exposed in the Millerstown quadrangle. At the Susquehanna River (Berry

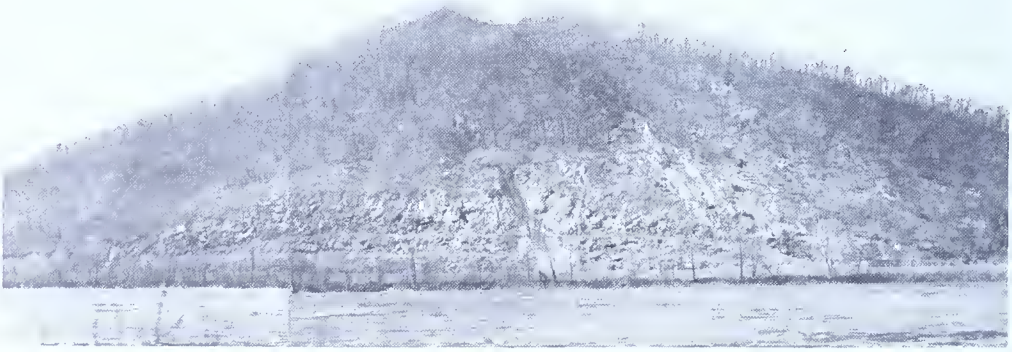


Figure 48. Pocono Formation exposed on the east end of Berry Mountain at the Susquehanna River. A nearly complete exposure of the Pocono can be seen on the terraces above the highway (U.S. Route 11-15) and on the mountain slopes. Width of view approximately three-fourths mile.

Table 21. *Thickness Values for the Pocono Formation in the Vicinity of the Millerstown Quadrangle*

Locality	Quadrangle*	County	Formation or member	Thickness (feet)	(meters)	Source
Buffalo and Berry Mtns.	Millerstown	Perry	Beckville and Mt. Carbon	1,165′	355 m	this report
			Spechty Kopf	435′	133 m	do.
			(total)	1,600′	488 m	do.
Berry Mtn. (Mt. Patrick)	Millersburg	Perry	Beckville	559½′	170 m	Hoskins., in prep.
			Spechty Kopf	435′	133 m	this report
Millersburg	Millersburg 7½′	Northumberland	Beckville and Mt. Carbon	1,508′	460 m	do.
			Spechty Kopf	209′	64 m	do.
			(total)	1,717′	524 m	do.
Clarks Ferry	New Bloomfield	Dauphin	Spechty Kopf	219′	67 m	Wood and others, 1963
Cove Mountain	Harrisburg	Perry	Pocono Fm.	1,600′	488 m	Cloos and Broedel, 1943

* Refers to 15-minute quadrangle unless otherwise stated.

Mountain), the basal contact of the Spechty Kopf Member is sharp and conformable, and is placed at the top of the uppermost upward-fining cycle of the Duncannon Member of the Catskill Formation.

Age

The Pocono Formation is both Upper Devonian and Lower Mississippian in age; the systemic boundary occurs in the Spechty Kopf Member (Read, 1955; Trexler and others, 1961).

Sedimentation

Regional sedimentological studies by Leonard (1953), Read (1955), Pelletier (1958), Wood and others (1969), and Sevon (1969b) indicate that the Pocono Formation was deposited principally in nonmarine environments such as stream and river valleys, floodplains, swamps, and lakes. The conglomerate lenses and beds, crossbedded sandstones, occasional grayish-red silty shales, and absence of marine fossils suggest that the Pocono is predominantly a fluvial deposit. The marginal marine and deltaic conditions which coexisted to the northeast (Sevon, 1969a) apparently did not extend to this area. The occurrence of carbonaceous shale beds and thin coal seams suggests that paludal conditions were locally present.

The petrography, pebble size distribution, and current indicators suggest that the Pocono formed on a coastal plain bounded on the southeast by a fall line (which roughly coincides with the present Pennsylvania-New Jersey border) and on the northwest (in west-central Pennsylvania) by a marine shoreline (Pelletier, 1958). Pelletier's measured crossbedding dip directions (from 227 outcrops) indicate a mean current direction to the west-northwest, at 290° azimuth.

The Pocono Formation constitutes part of the Late Paleozoic molasse, a great wedge of predominantly nonmarine clastic sediments which accumulated in response to an uplift to the southeast.

MISSISSIPPIAN SYSTEM

Mauch Chunk Formation

Name and Extent

The thick sequence of predominantly red clastic sedimentary rocks which overlies the Pocono Formation in central Pennsylvania, originally termed the Umbral Series, Formation XI by Rogers (1859), was named the Mauch Chunk by Lesley (1876). The Mauch Chunk has been subdivided into three informal members elsewhere in central Pennsylvania (Hoskins, 1963; Wood and others, 1969), based primarily on the presence of nonred sandstones and conglomerate beds in the upper and lower members. Although two mappable nonred sandstones occur low in the Mauch Chunk in the Millerstown quadrangle, they are of limited areal extent and thus the Mauch Chunk is not subdivided here. Only the lower half to one third of the Mauch Chunk is present here; these are the youngest beds present in the quadrangle.

The Mauch Chunk Formation is recognized from northeastern Pennsylvania to western Maryland, West Virginia, and eastern Ohio.

Character

The Mauch Chunk is predominantly an interbedded sequence of grayish-red siltstones and silty shales, with two nonred sandstones and conglomeratic sandstones in the lower portion. The siltstones, which are locally olive gray, are argillaceous and thin to medium bedded, and constitute approximately one-third of the exposed section. The shales are thin to massive bedded and comprise one-half to two-thirds of the section. The sandstones are mainly grayish brown, medium to coarse grained, thin to thick bedded, crossbedded and locally conglomeratic. The conglomerate fraction consists of predominantly light gray to white quartz and quartzite pebbles, with occasional siltstone and shale fragments. The pebbles are angular to subrounded and generally range in size from 1/4 to 1 inch (.6 to 2.5 cm), but are occasionally up to 4 inches (10 cm) wide.

Trough-type crossbedding is commonly present in the sandstones and conglomerates, and scattered measurements suggest a north to northwest paleocurrent direction. Groove casts are rare and have an average trend of 305° azimuth.

Outcrop Area and Thickness

The Mauch Chunk Formation occurs only between Buffalo and Berry Mountains in the southeastern part of the Millerstown quadrangle, in the hinge of the Buffalo-Berry synclinorium.

The thickness of the Mauch Chunk exposed in the quadrangle is estimated at 2000 feet (610 m), constituting perhaps the lower third to lower half of the entire formation. Estimates of its total thickness in central Pennsylvania range widely, from 2400 to 7000 feet (732 to 2134 m; Hoskins, 1963) to 3000 to 7500 feet (914 to 2286 m; Wood and others, 1969). The nearest Mauch Chunk measured section is at West Branch Gap in Second Mountain (Pottsville quadrangle, Schuylkill County), some 42 miles (68 km) east of the Millerstown quadrangle. At that locality the Mauch Chunk is 3716 feet (1133 m) thick (Wood and others, 1969).

Formation Boundaries

The contact of the Mauch Chunk Formation with the underlying Pocono Formation is not exposed in the Millerstown quadrangle; in the Millersburg quadrangle to the east, it is conformable and gradational within a few feet.

Age

The Mauch Chunk Formation is Late Mississippian in age (Chesterian Series) according to Weller (1948). Arndt and others (1959) and Wood and others (1969) concluded that the Mississippian/Pennsylvanian systemic boundary lies in the upper part of the Mauch Chunk Formation in the southern and western anthracite basins. However, that portion of the Mauch Chunk which is preserved in the Millerstown quadrangle is evidently below this horizon.

Sedimentation

The dominant red color, the rather fine grain size of the clastic sediments, the presence of plant fossils, and the absence of marine fossils suggest that the Mauch Chunk was deposited on a broad floodplain or coastal plain. The limited areal extent of the coarser sediments (the sandstones and conglomeratic sandstones) suggests that these may have been deposited in either river channels or distributary channels on the floodplain or as alluvial fans. This origin for the Mauch Chunk was first proposed by Barrell (1907) and has been concurred with by Hoque (1968) and Wood and others (1969).

Hoque (1968) suggested that the Mauch Chunk in south-central and western Pennsylvania was formed in an elongate molasse basin in which terrigenous sediments thin seaward (toward the west) and thicken toward the source region (eastward). This model is striking for its similarity to that inferred for the Juniata, Tuscarora, Catskill, Pocono, and Pottsville Formations, indicating that similar relationships of source and depositional areas, dispersal systems, paleogeography, and basin tectonics recurred several times in the central Appalachians during the Paleozoic era.

STRUCTURAL GEOLOGY

INTRODUCTION

The dominant structures in the Millerstown quadrangle are folds. The two major anticlines and two major synclines which cross the quadrangle are portions of first-order (Nickelsen, 1963) anticlinoria and synclinoria which extend the length of the Valley and Ridge province from south-central to northeastern Pennsylvania (Figure 49). Numerous smaller folds

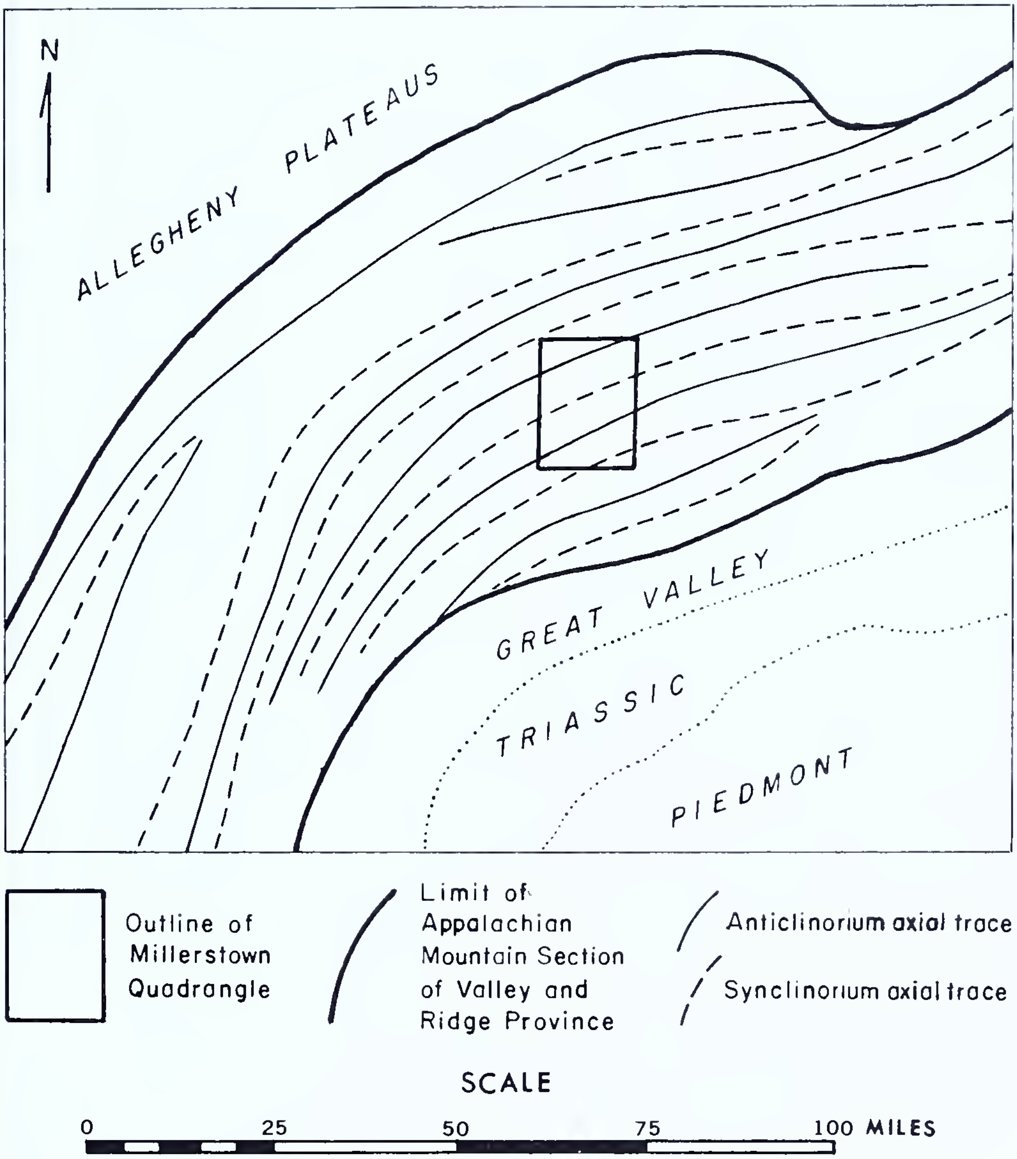

N
ALLEGHENY PLATEAUS
GREAT VALLEY
TRIASSIC
PIEDMONT
Outline of Millerstown Quadrangle
Limit of Appalachian Mountain Section of Valley and Ridge Province
Anticlinorium axial trace
Synclinorium axial trace
SCALE
0
25
50
75
100 MILES

Figure 49. Generalized tectonic map of the Valley and Ridge province in central Pennsylvania.

(second-order) occur within the limbs and hinges of the major folds, imparting considerable complexity to the major, first-order folds. Even smaller (third- and fourth-order) folds occur throughout the quadrangle, a number of which can be observed in single outcrops.

Kink bands, parallel-sided zones of rotated beds newly recognized in the Valley and Ridge province (Faill, 1969), occur in a wide range of sizes and are the basic structural element which explains the geometries of the folds.

Faults constitute a subordinate part of the structure, and for the most part are reverse wedge faults. They are intimately related to the folds, representing local disruptions that occurred during the folding process.

Cleavage is only poorly developed in some of the shales and shaly limestones and is generally not a significant feature in the rock exposures.

STRUCTURES OBSERVED IN OUTCROP

Folds

The folds within this quadrangle are flexural-slip folds. The beds do not change thickness appreciably across the folds, indicating that very little deformation has occurred within the individual beds. The common occurrence of slickensides on the bedding surfaces indicates that the principal deformational mechanism was slip on the bedding surfaces between the beds.

Simple Folds

Although the folds are flexural-slip folds, they are not concentric (parallel) folds in which the beds are uniformly bent throughout the fold. Rather, they possess a distinctive cross-sectional geometry that appears to be characteristic of most folds throughout the Valley and Ridge province. Within each fold limb, the bed attitude is constant and the beds are not bent (Figure 50)—only in the hinge are the beds bent, and the width of this hinge is narrow with respect to the dimensions of the fold (Figure 51). This geometry, which occurs in the smallest to the largest of the folds, can be inferred by the constant bed attitude from one outcrop to the next within single fold limbs, and by the relatively abrupt changes in orientation within short distances across the fold hinges (Figure 52).

For example, the southern limb of the Tuscarora anticlinorium (between the Tuscarora and Buffalo-Berry hinges) is relatively simple and well exposed along the Juniata River, with only one fault-fold structure (at Wildcat Ridge) interrupting the homoclinal aspect of the bedding (see Plates 1 and 2). The hinge of the Tuscarora anticlinorium appears to be concentric (Figure 53). However, the wavelength of this fold is approximately 9 miles (14.5 km), whereas the radius of curvature in the hinge is only 0.8 mile (1.3 km). (In concentric folds, the radius of curvature must be at least one-half of the wavelength.) Similarly, the radius of curvature of the hinge of the Buffalo-Berry synclinorium is only 0.6 mile (1 km). Thus the hinges of both of these folds are narrow with respect to the wavelengths. With such small radii of curvature, and large structural relief, it is evident that a concentric-fold model cannot apply to these large folds.

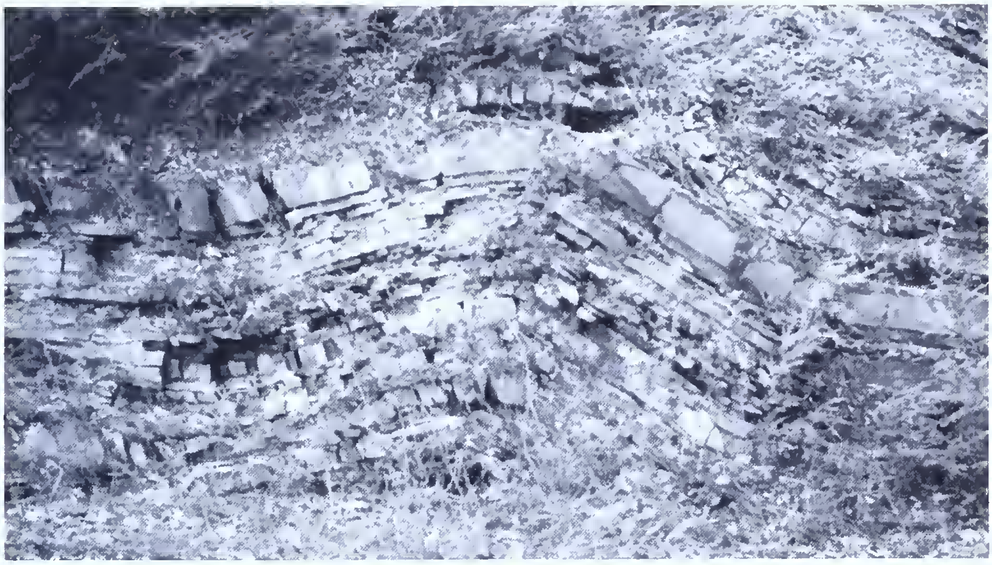


Figure 50. Small open fold exhibiting the planar bedding in the fold limbs and the narrow hinge that is characteristic of most Valley and Ridge folds. Mahantango Formation (Montebello Member), in roadcut on south side of Cocolamus Creek in Juniata County, 1 mile north-northwest of Wardville, Perry County.

Another feature of concentric folds is the progressive increase in bedding dip away from the hinges to a maximum in the middle of the fold limb. Within one-half mile south from the Tuscarora hinge, the bedding dip increases to 55 degrees (Plate 1). For the next 3.5 miles (5.6 km) to the southeast, the bedding dip remains moderately steep between 30 and 55 degrees (with some local exceptions which reflect minor folds or kink bands within the major limb). The progressive decrease in dip occurs only within 0.5 mile (0.8 km) of the Buffalo-Berry hinge. Thus the major fold reflects the other principal feature observed in smaller folds—a relatively constant bed orientation within the fold limb.

The "tightness" of the folds varies, ranging from open folds (interlimb angle of 125 to 175 degrees, e.g., Figure 50) to tight (interlimb angle from 45 to 125 degrees, as in Figure 54). Brecciation of beds at the hinge is absent, even in quartzite beds. However, small-scale faulting of one or two beds in a hinge is not uncommon.

Fold axes measured at outcrops plunge gently, both to the northeast and southwest (Figure 55), having a mean statistical plunge of 3 degrees to N70E. Most of the larger folds in the quadrangle, as well as the major anticlinoria and synclinoria, also plunge gently to the northeast.

Data on the orientation of axial surfaces are sparse, because exposures are not large enough, relative to the width of the fold hinges, for good

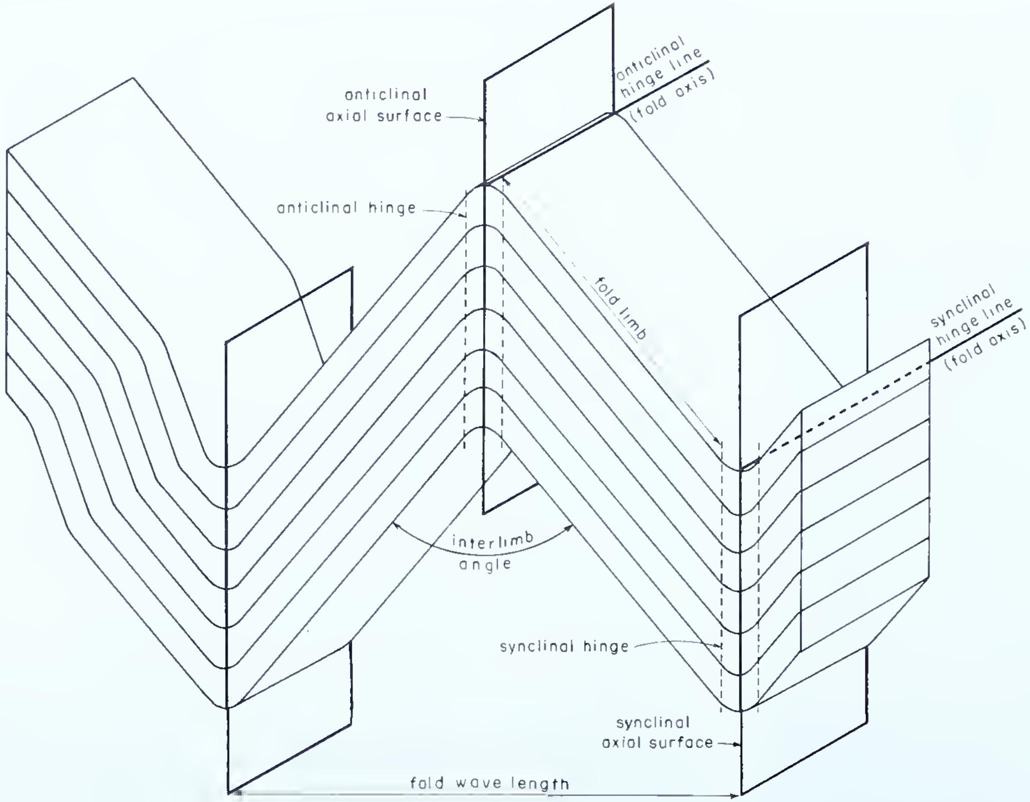


Figure 51. Fold geometry characteristic of Valley and Ridge folds, and fold terminology used in this report. The *fold axis* is the line which, moved parallel to itself in space, generates the fold form (McIntyre, 1950). The *hinge line* is the line in the folded surface about which the attitude of the surface changes most abruptly from one limb to another. In *cylindrical folds*, the hinge line and fold axis are parallel. The fold *hinge* is the portion of the fold having maximum curvature. The *axial surface* is the surface which passes through all the hinge lines in a fold. The *axial trace*

is the intersection of the axial surface with the earth's surface. The fold axis possesses only orientation, whereas the axial surface and hinge line possess position as well as orientation. A *fold limb* comprises all the rocks between two adjacent fold hinges. A *fold* consists of two fold limbs and the intervening hinge. An *anticline* includes all the rocks between two adjacent synclinal hinges; a *syncline* includes the rocks between two adjacent anticlinal hinges. Thus an anticline-syncline pair possess a common limb. The *fold wavelength* is the distance between two adjacent anticlinal (or synclinal) axial surfaces. The *interlimb angle* is the angle between the bed orientations of two adjacent fold limbs. (See Donath and Parker, 1964, for further discussion of folds and fold terminology.)

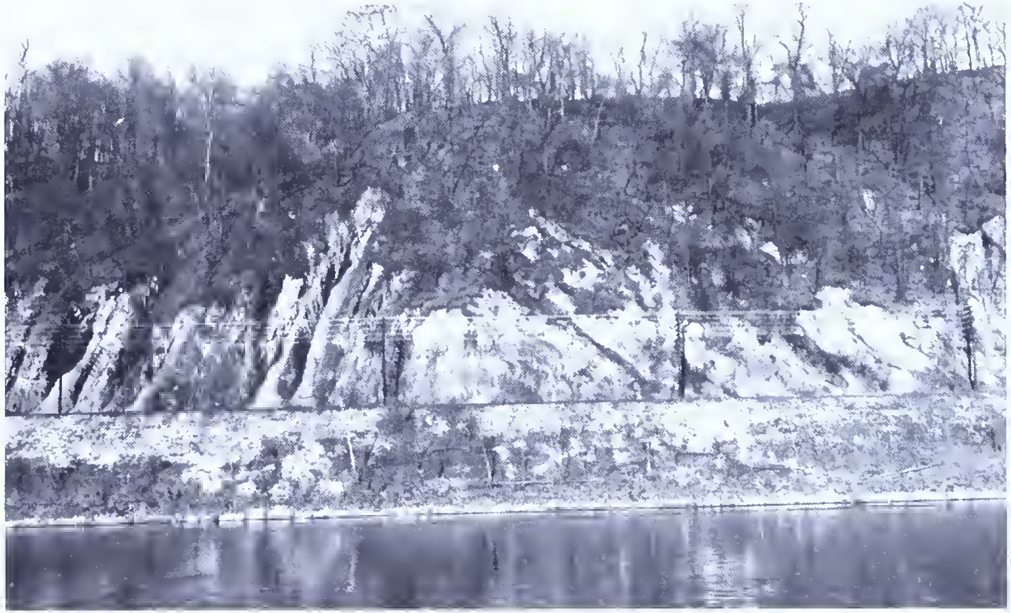


Figure 52. Anticline typical of Valley and Ridge folds, possessing planar bedding in the limbs and a narrow hinge. Wills Creek Formation, in Penn Central Railroad cut on west side of the Juniata River, 0.75 mile south of Mifflin, Juniata County.

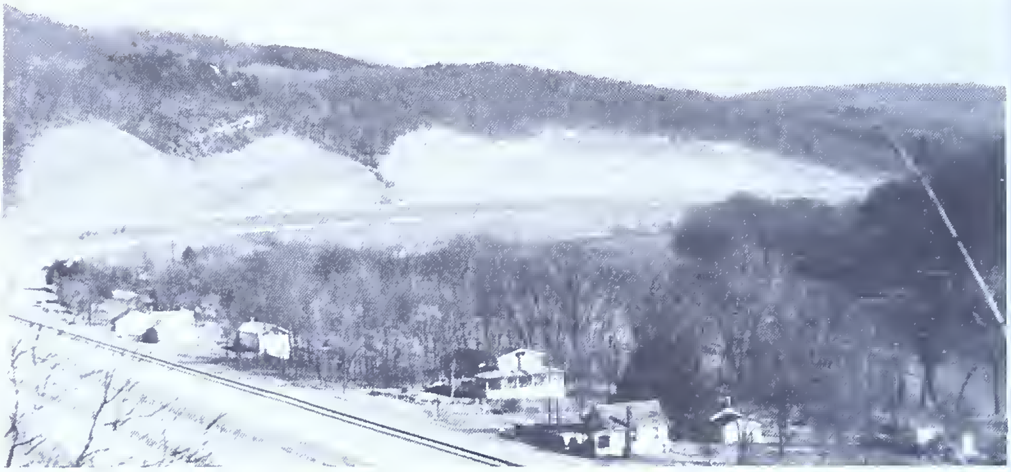


Figure 53. Hinge of the Tuscarora anticlinorium. The rather uniform curvature of beds within this exposure suggests a concentric fold, but the radius of curvature is much less than the fold wavelength, indicating that the hinge is narrow with respect to the entire fold. Tuscarora Formation, U.S. Route 22-322 on the east side of the Juniata River, 1 mile north of Millerstown, Perry County.

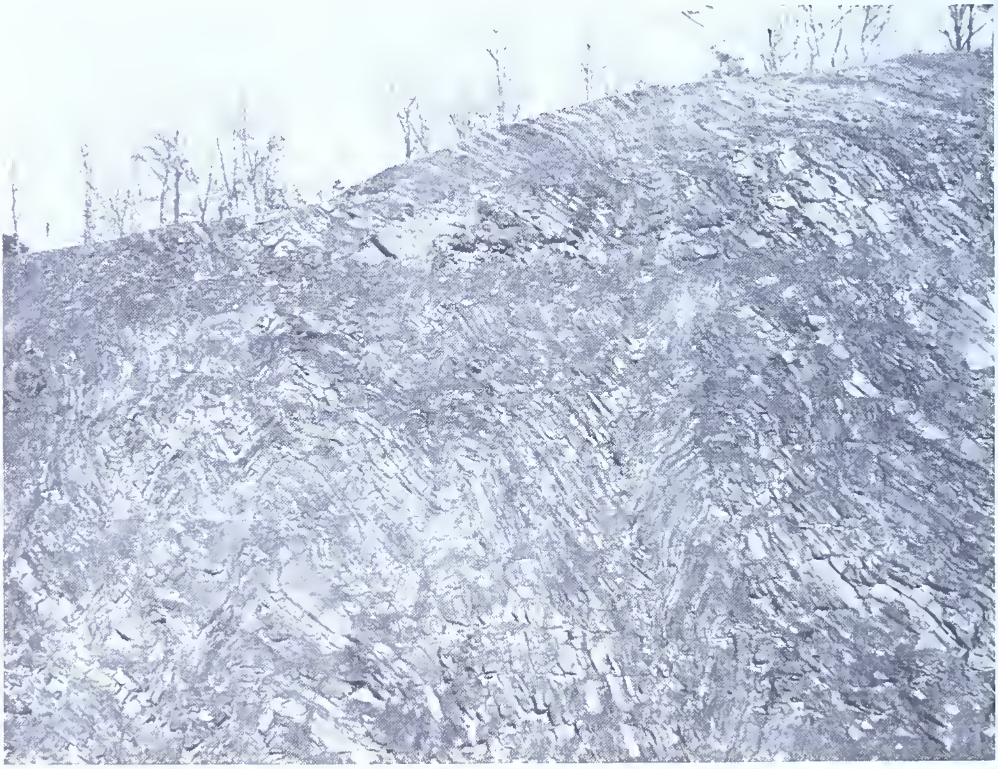


Figure 54. Tight folds in the Trimmers Rock Formation (interlimb angle less than 125 degrees). Roadcut on U.S. Route 22-322 (southbound lane), 2.5 miles north of Amity Hall, Perry County.

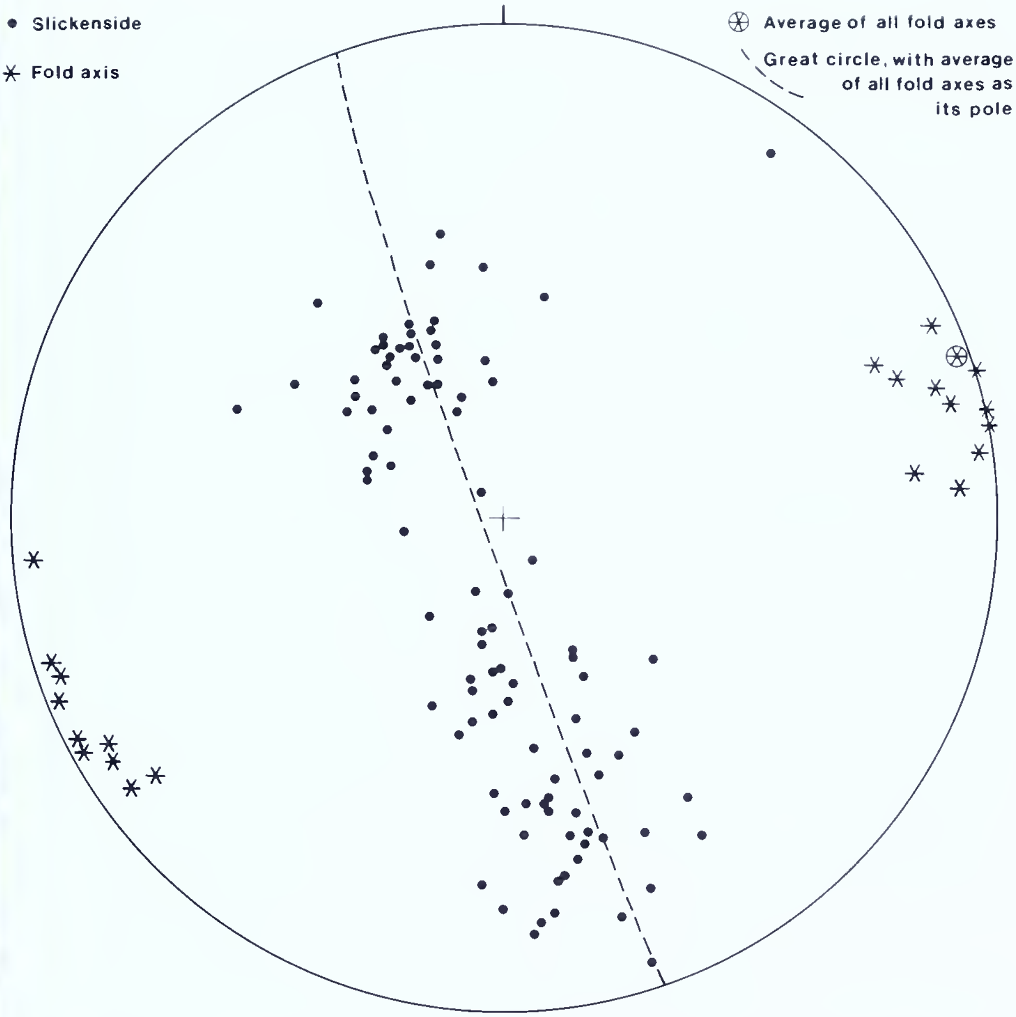


Figure 55. Fold axes and slickensides on bedding surfaces measured in the Millerstown quadrangle. (This stereographic projection is an equal-area projection, as are all the others in this report.)

measurements. The axial surfaces tend to be subvertical, dipping either northwest or southwest at 70 degrees or more. Without better data on the orientation of the axial surfaces, it is not possible to ascertain whether the folds are inclined predominantly to the northwest or to the southeast. There are a few small folds within the limbs of larger folds which are less steeply inclined (Figure 50).

Conjugate Folds

Conjugate folds are folds with two axial surfaces inclined toward each other (Figure 56). These folds possess many of the attributes of simpler

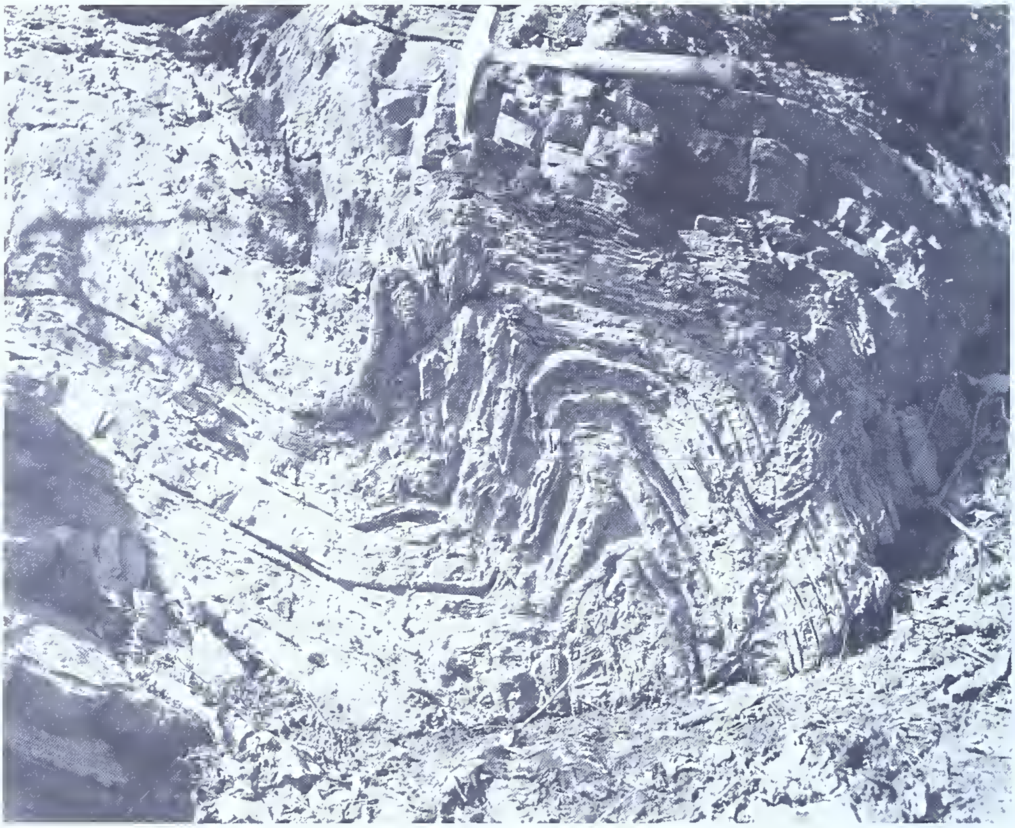


Figure 56. Conjugate fold in the Wills Creek Formation on west bank of the Juniata River at Charlies Hill, 5.5 miles northwest of Huntingdon, Huntingdon County.

folds with single axial surfaces. Bedding in the limbs is planar, and the hinges are narrow with respect to the fold wavelength. The tightness of conjugate folds is comparable to that of the simple folds. The fold axes plunge gently to the northeast or southwest, and the folds are not greatly inclined. The significant difference is that conjugate folds have two sets of hinge lines rather than one; thus, instead of possessing only two limbs, an additional central, relatively unrotated *interlimb* exists between the two axial surfaces.

The simple fold and the conjugate fold are actually two different parts of the same fold structure (Figure 57), although not every simple fold has a conjugate fold above it. Conjugate folds occur where the single axial surface of a simple fold bifurcates (upward for anticlines, downward for synclines) into two axial surfaces.

Kink Bands

A kink band is a parallel-sided zone of rotated beds (Figures 58 and 59). Kink bands are rather common in the rocks in the Millerstown

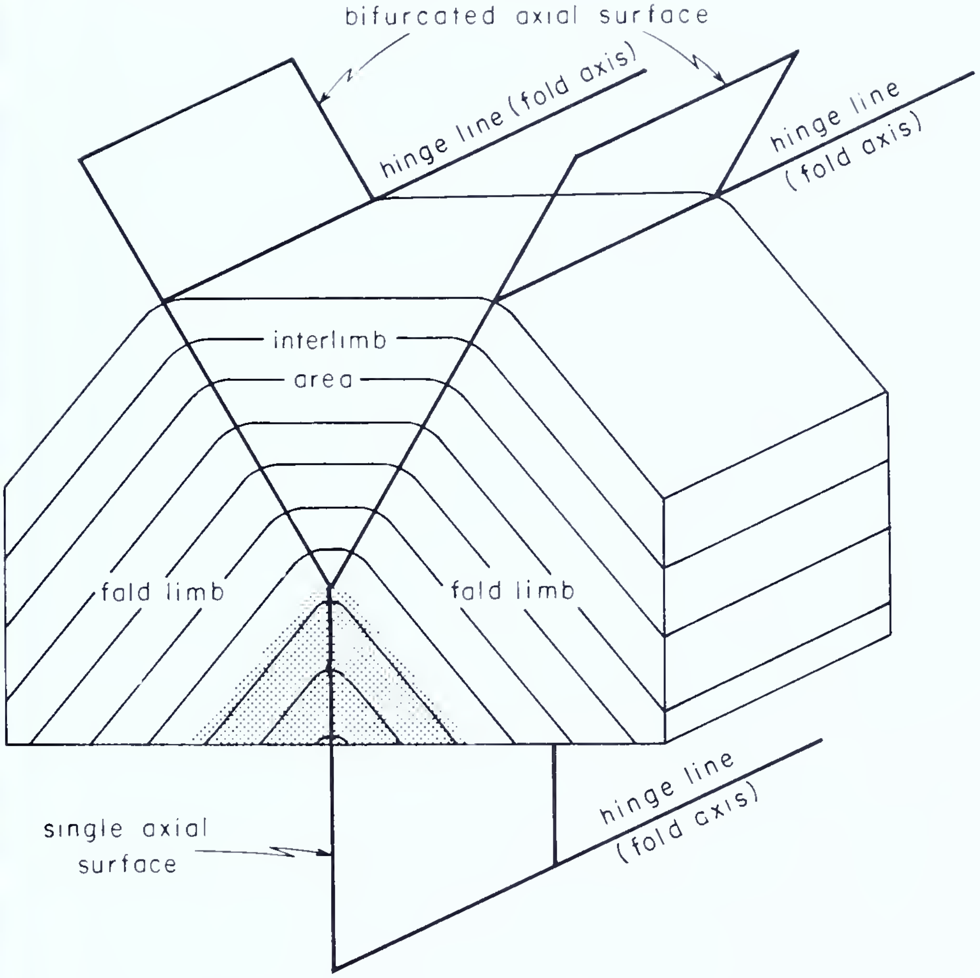


Figure 57. Idealized relation between simple (stippled) and conjugate (unstippled) anticlinal folds.

quadrangle and, as observed in outcrops, range from 1 inch to 50 feet (2.5 cm to 15+ m) wide. Larger kink bands can be observed in exceptionally large exposures, and they can be mapped. Bedding usually possesses the same orientation on each side of the kink band, although occasionally the bed orientation is different.

Apparently kink bands do not occur preferentially within beds of particular orientation, for they have been observed in horizontal and vertical beds, as well as in moderately dipping beds. Characteristically, the kink planes are at moderate to large angles to the bedding outside the kink band (the enclosing bedding attitude). Of those measured, the angle ranges from 40 to 90 degrees, averaging 62 degrees.

The orientations of the kink planes range from horizontal to vertical. Although the kink planes dip in different directions, the poles to the kink planes that have been measured fall on a great circle, and the pole of this great circle plunges 5 degrees to N65E (Figure 60), close to the

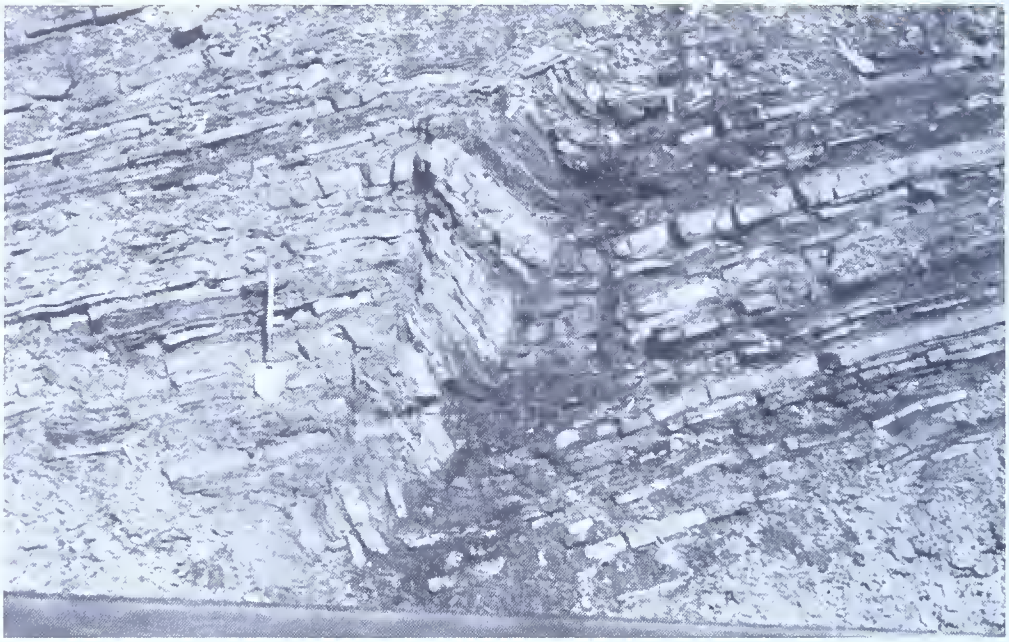


Figure 58. Moderately north dipping, 1.5-foot-wide kink band. Rose Hill Formation, in roadcut on Pa. Route 103, 1.7 miles southwest of Lewistown, Mifflin County.

mean fold-axis orientation. The kink axes also plunge gently to the northeast (and occasionally to the southwest) (Figure 60).

Kink-Band Folding

The similarity of cross-section profile and three-dimensional geometry between the folds and the kink bands has engendered the concept of kink-band folding—the development of a fold geometry from a suitable array of kink bands (Faill, 1969 and 1973). Both kink bands and folds possess planar elements separated by narrow zones within which bedding is sharply bent. There is also a geometrical congruence between the two types of structures with respect to fold axes, kink axes, and planar features (fold axial surfaces and kink planes) (Figures 55 and 60).

The concept of kink-band folding is that the basic structural element is the kink band, and every fold can be generated by a combination of two kink bands. The two kink bands must be inclined toward each other, must have opposite senses of bed rotation, and must join or intersect each other (Figure 61). Where the kink bands join, a fold results with the profile characteristic of Valley and Ridge folds. The surface of junction between the two kink bands is the axial surface of the fold. A conjugate fold geometry occurs in that part of the structure where the

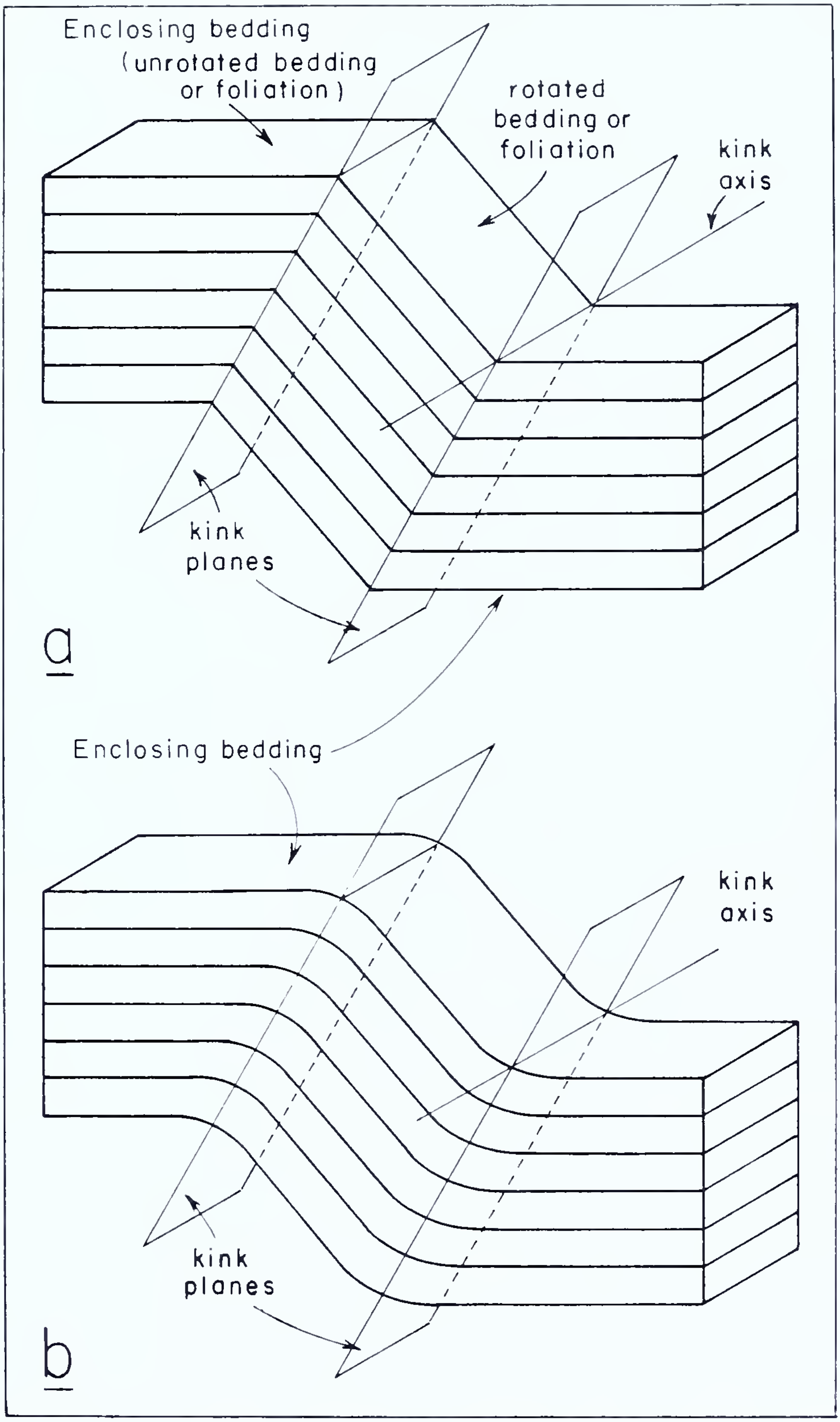


Figure 59. A. Ideal kink band, consisting of a zone bounded by kink planes, transecting bedding, within which the bedding has been rotated about the kink axis.
B. Essentially identical to A, except that the bedding is not as sharply flexed.

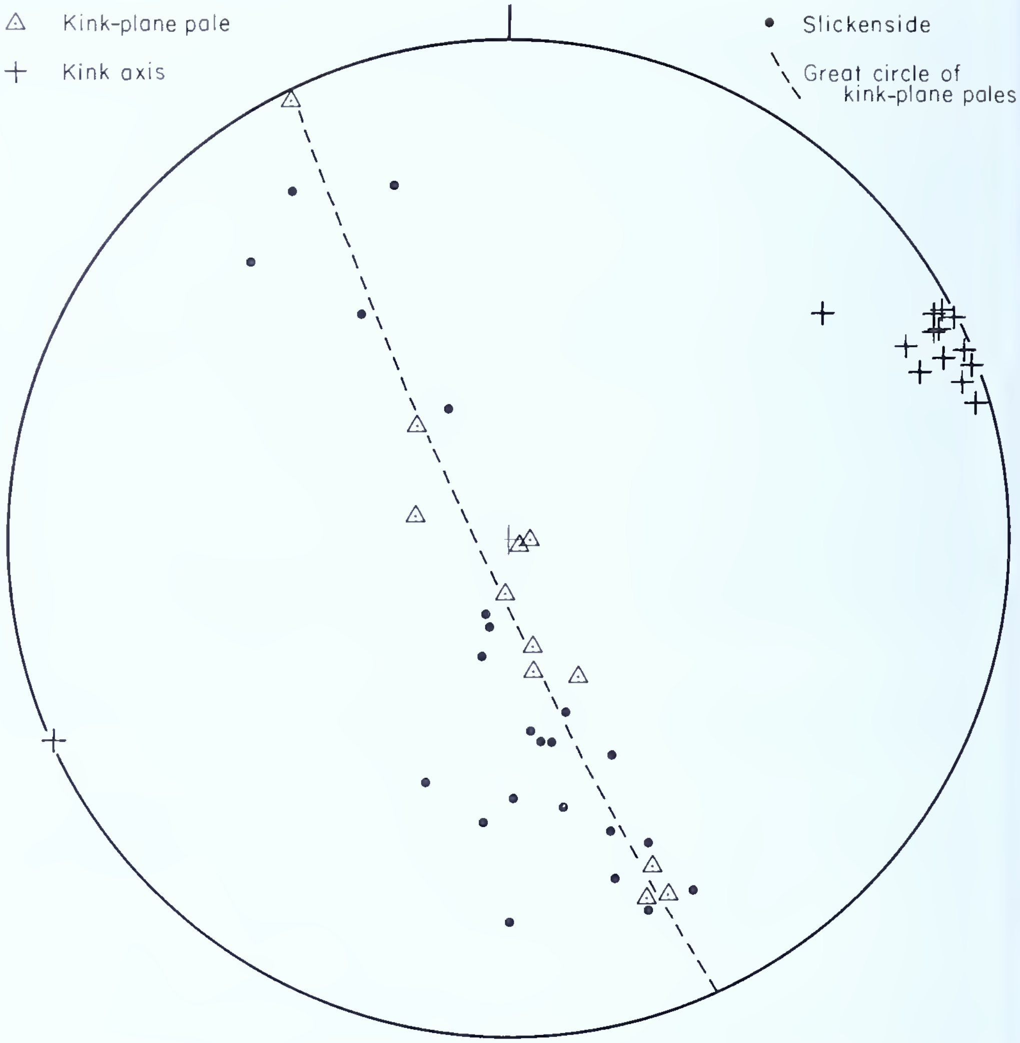


Figure 60. Kink axes, kink planes, and slickensides on bedding within kink bands, measured in the Millerstown quadrangle.

kink bands are separated by relatively nonrotated beds, a zone called the *interlimb*. Thus the simple and conjugate folds are but two different parts of the same kink-band structure.

Where the two kink bands are of equal width, of equal inclination to the enclosing bedding attitude, and have equal (and opposite) amounts of bed rotation, the resultant fold is upright (the axial surface is perpendicular to the enclosing bed attitude) and symmetric (each limb is the mirror image of the other limb) (Figure 62A). Variations of width, inclination, and amount of bed rotation between the two kink bands result in folds that are asymmetric (the limbs are not mirror images of each other, as in

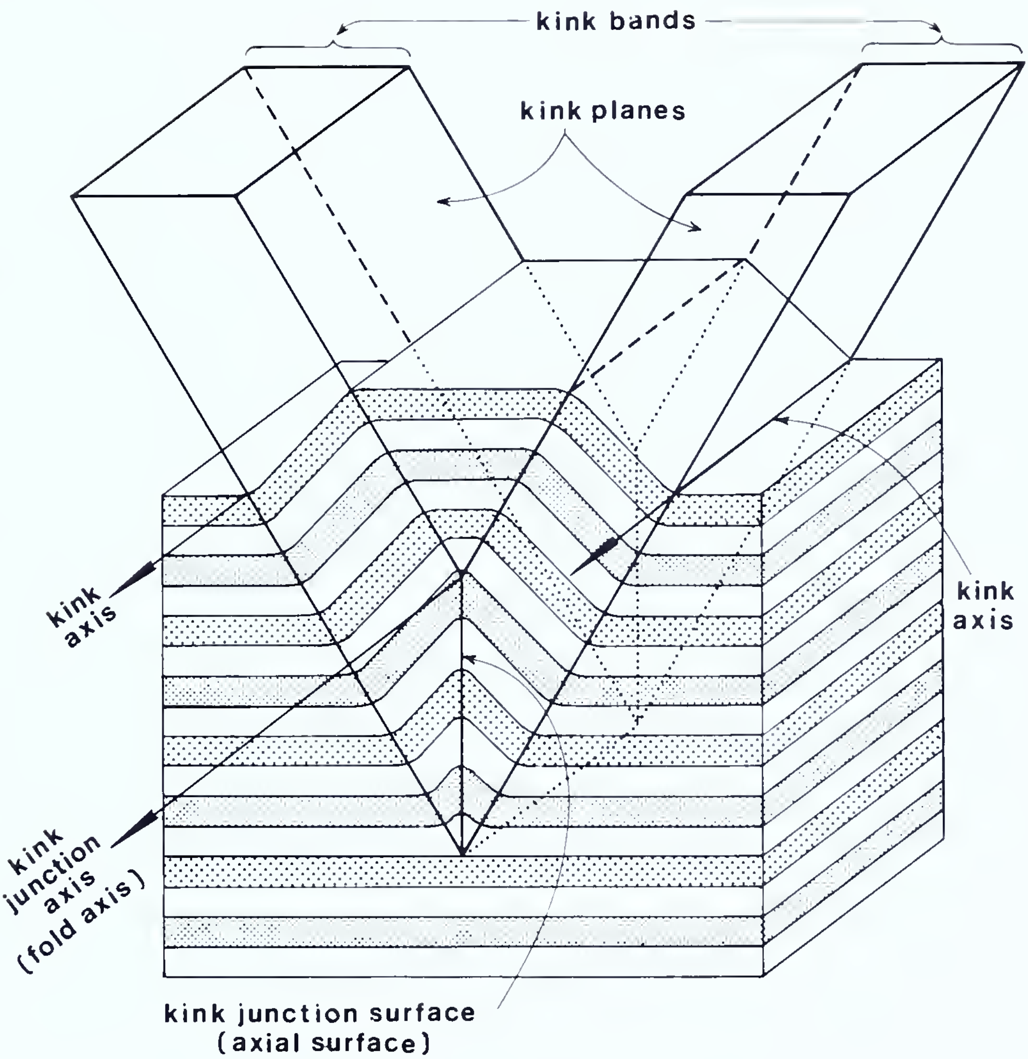

kink bands
kink planes
kink axis
kink axis
kink junction axis (fold axis)
kink junction surface (axial surface)

Figure 61. Ideal geometry of a kink-band fold. Where two kink bands join or intersect, a fold develops which possesses all the geometrical features typical of Valley and Ridge folds. The surface of junction between the two kink bands is the axial surface of the fold; the intersection of the kink planes is the fold axis, which parallels the two kink axes in cylindrical folds.

Figure 62B) or inclined and asymmetric (the axial surface is not normal to the enclosing bedding, as in Figure 62C). Inclination of the fold axial surface (i.e., a nonvertical axial surface) does not necessarily imply that the fold is asymmetric. Symmetry of a fold is defined only by the internal geometry and has nothing to do with its orientation. For example, in Figure 62D, the fold is recumbent (because the axial surface is hori-

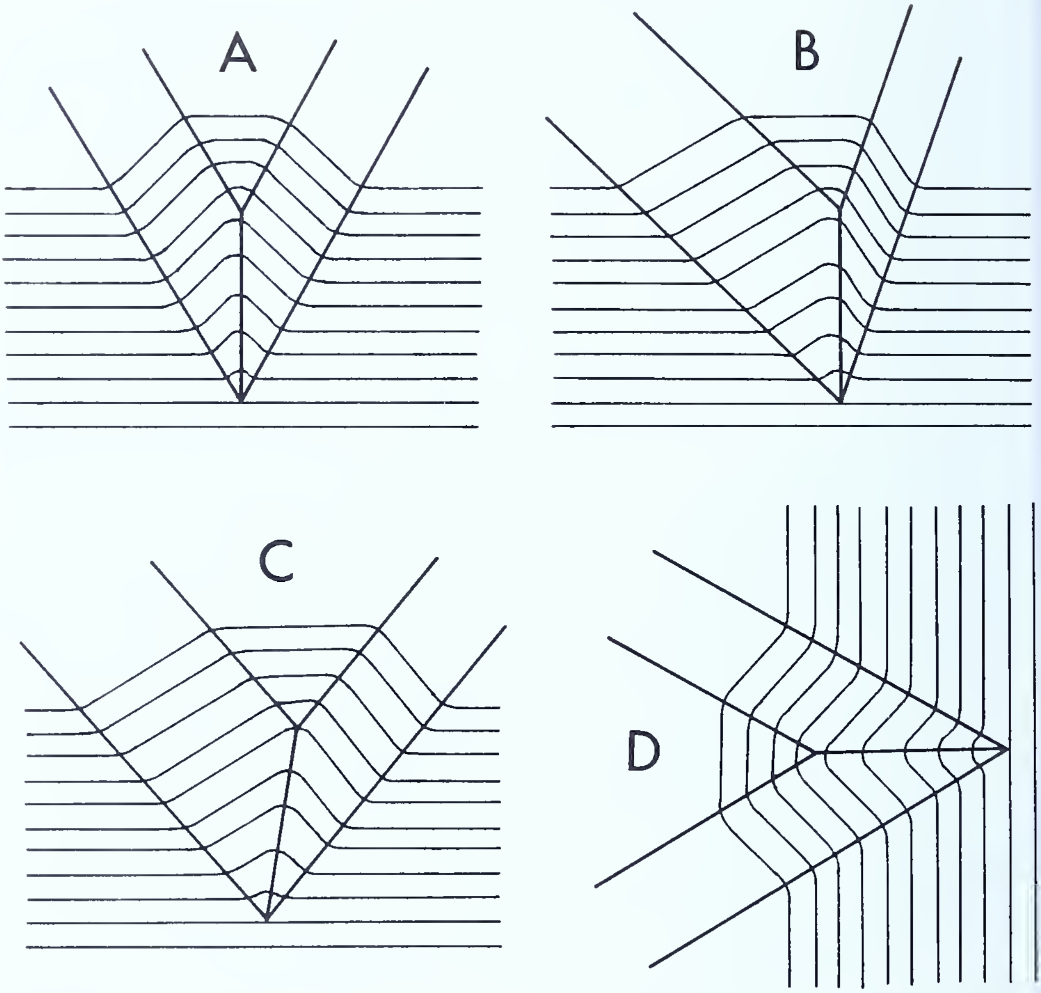


Figure 62. Varying fold geometry as a result of varying kink-band geometry.

A. The two kink bands are of equal width, at the same angle to the enclosing bedding, and possess the same amount of bed rotation within them. The resulting fold is symmetric with the axial surface normal to the enclosing bedding (the fold is upright).

B. The kink band on the left is wider, at a smaller angle to the enclosing bedding, and possesses less rotation of bedding within it as compared to the one on the right. Although the fold is asymmetric, the axial surface is normal to the enclosing bedding (the fold is upright).

C. Similar to B, except that the axial surface is oblique to the enclosing bedding. The fold is both asymmetric and inclined.

D. Identical to A with respect to internal geometry. However, because the enclosing bedding is vertical, the axial surface is horizontal. Thus, this fold is symmetric and recumbent.

zontal), but is perfectly symmetric (see also Figure 50, an inclined, symmetric anticline).

Valley and Ridge terrain does not consist of simple and conjugate folds isolated from each other by horizontal, unrotated beds. Rather, most of the rocks dip at some considerable angle and thus belong to one fold or another. A continuously folded terrain can be created by increasing the widths and density of the kink bands, and a complex arrangement of kink bands results in a complex pattern of folds (Figure 63). The presence of smaller kink bands within larger kink bands gives rise to smaller folds in the limbs and hinges of the larger folds. The fold geometry expressed by a given bed is dependent on the bed's position in the kink-band structure. If the bed traverses a few large, simple kink bands, the resultant folds are large and simple with considerable structural relief. Thus, in a single cross section, beds in one part of a stratigraphic section may exhibit a quite different fold geometry. This obtains not as a function of lithology or depth, but purely as a function of position within the kink-band array.

Folds change in geometry along trend as well as in vertical section. If the two kink bands in a fold are parallel, then the cross-sectional geometry of the fold will not change along the fold trend (and the fold is cylindrical). On the other hand, if the two kink bands are not parallel, then, in the direction of their convergence, they will cancel each other out and the fold will diminish in size and vanish (the fold is noncylindrical) (Figure 64). In the opposite direction, the fold enlarges and either becomes conjugate, or additional kink bands increase the complexity of the structure.

A particularly good example of the change in fold geometry along trend occurs in the anticline-syncline pair in the western and central part of the quadrangle, from Cocolamus to Kellerville (see also Faill, 1969). A block diagram (Figure 65) of the fold pair shows the folds diminishing and vanishing toward the northeast. On the western end, the anticline is conjugate. The kink-band model used to explain this fold geometry consists of two north-dipping kink bands and an intervening south-dipping kink band (Figure 66). The various fold geometries observed in the field (conjugate and simple folds, the diminution of the anticline) are present in the kink-band model. However, to produce the eastward diminution of the syncline along with the anticline, it is necessary to assume that the northernmost kink band trends in a more easterly direction than the other two (i.e., that the kink bands are not parallel). In this way, the two north-dipping kink bands converge toward the east (Figure 67), pinching out the intervening south-dipping kink band and thus producing the eastward diminution and termination of the anticline-syncline pair.

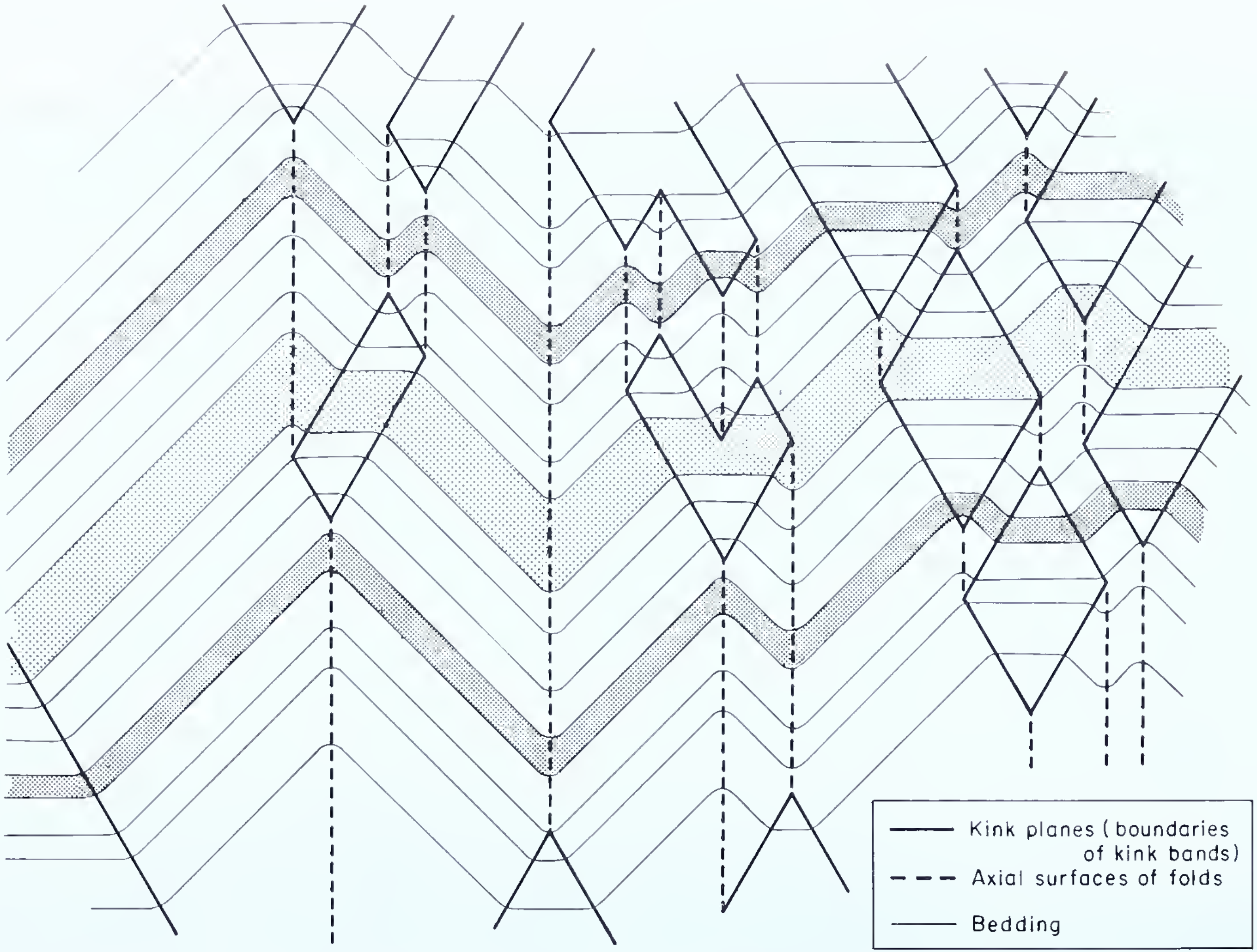


Figure 63. Hypothetical complex kink-band array and resulting fold profiles. In a single cross section, two different beds can express quite different fold profiles, depending upon the particular size and arrangement of the kink bands they pass through. The lower beds pass through a few large kink bands, and exhibit large folds of large structural relief; the upper beds pass through more, smaller kink bands, and exhibit smaller folds of lesser structural relief.

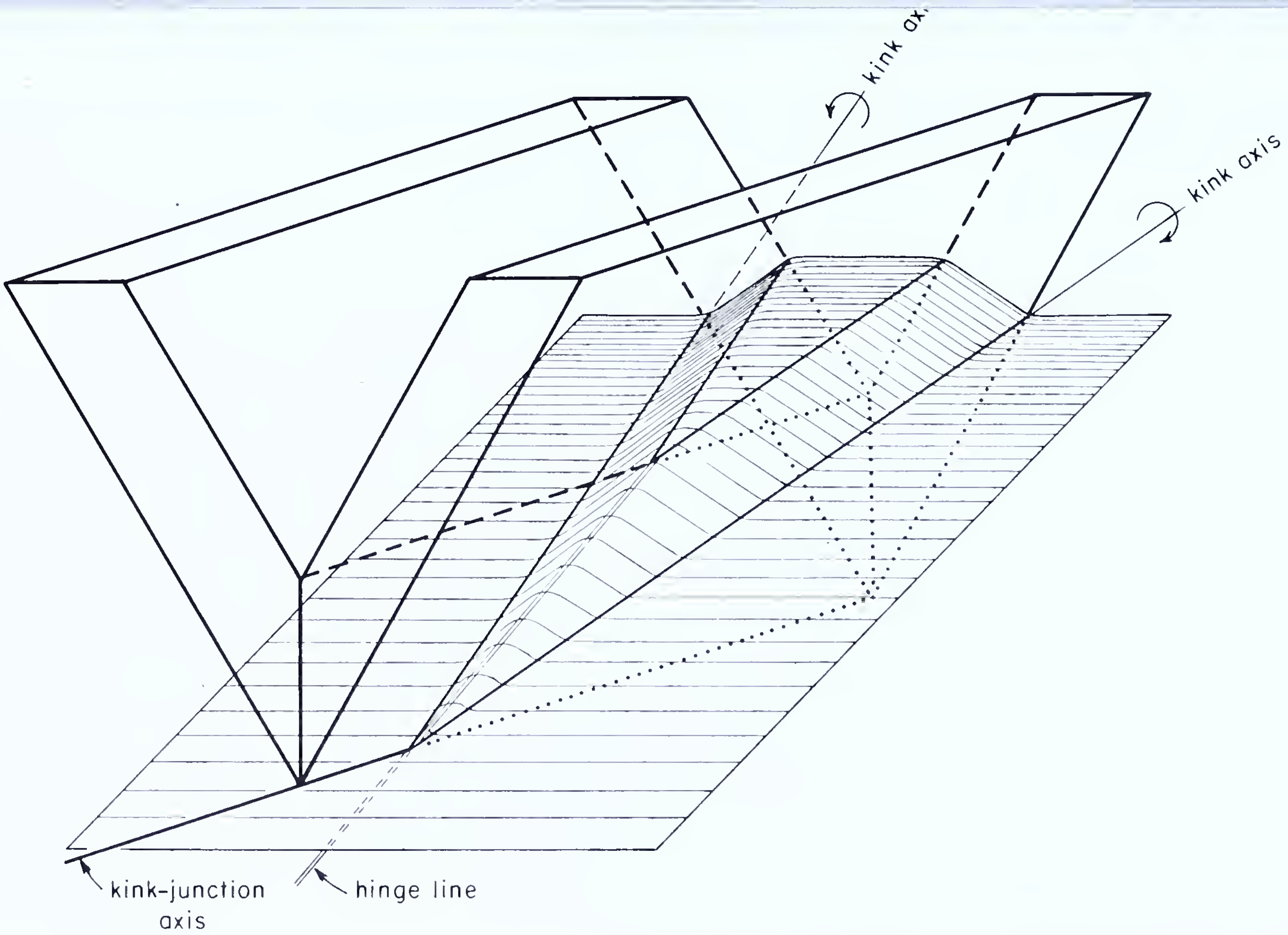


Figure 64. Noncylindrical fold produced by two nonparallel kink bands. The intersection of the kink bands, the kink junction axis, does not lie in the enclosing bedding. Thus, the two kink axes are not parallel, and the hinge line plunges toward the foreground. The fold diminishes to nothing toward the foreground, and changes into a conjugate fold toward the background.

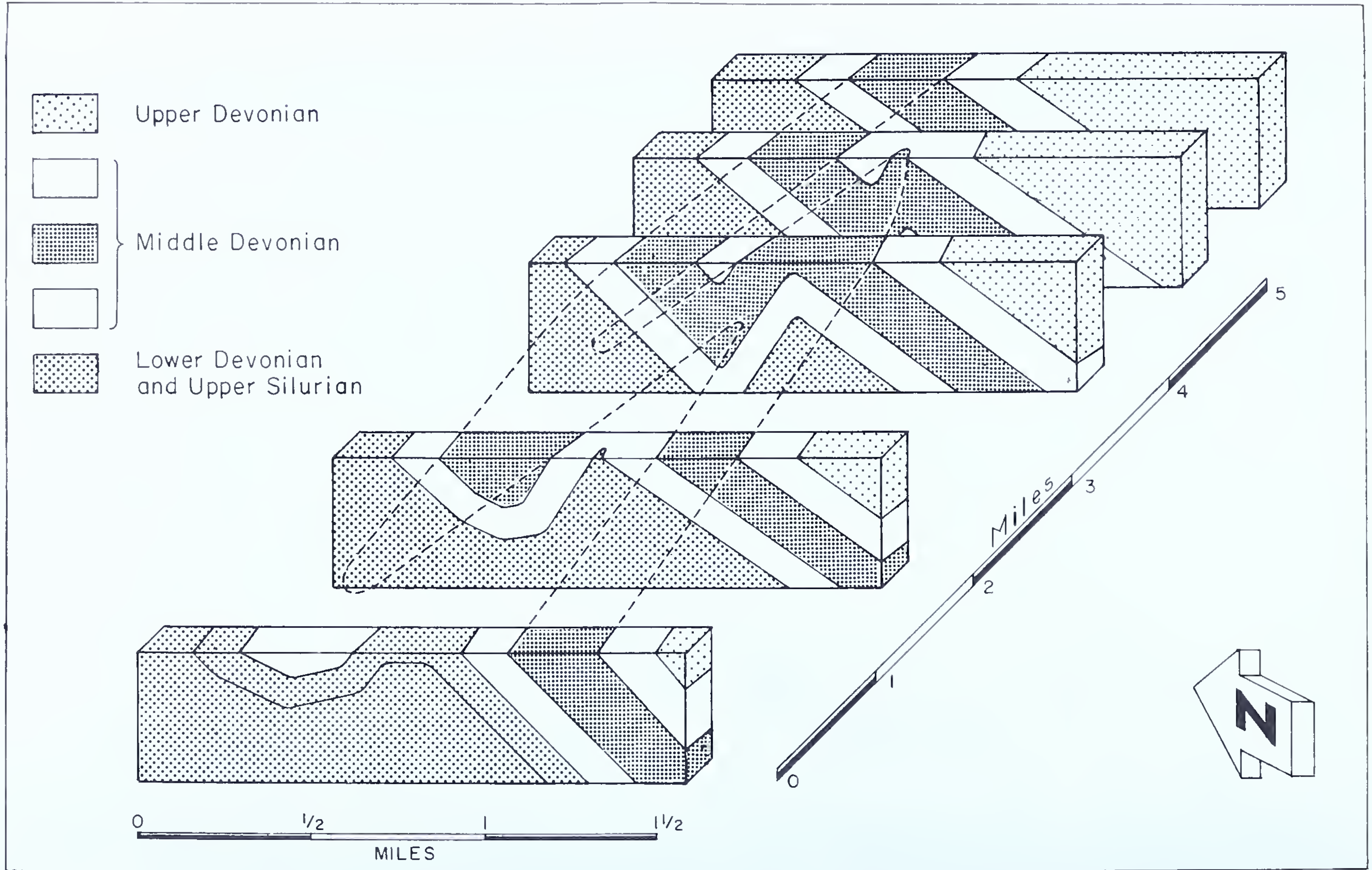


Figure 65. The Cocolamus structure in the western and central portions of the Millerstown quadrangle, illustrating the inferred fold geometries at depth and the changes along trend.

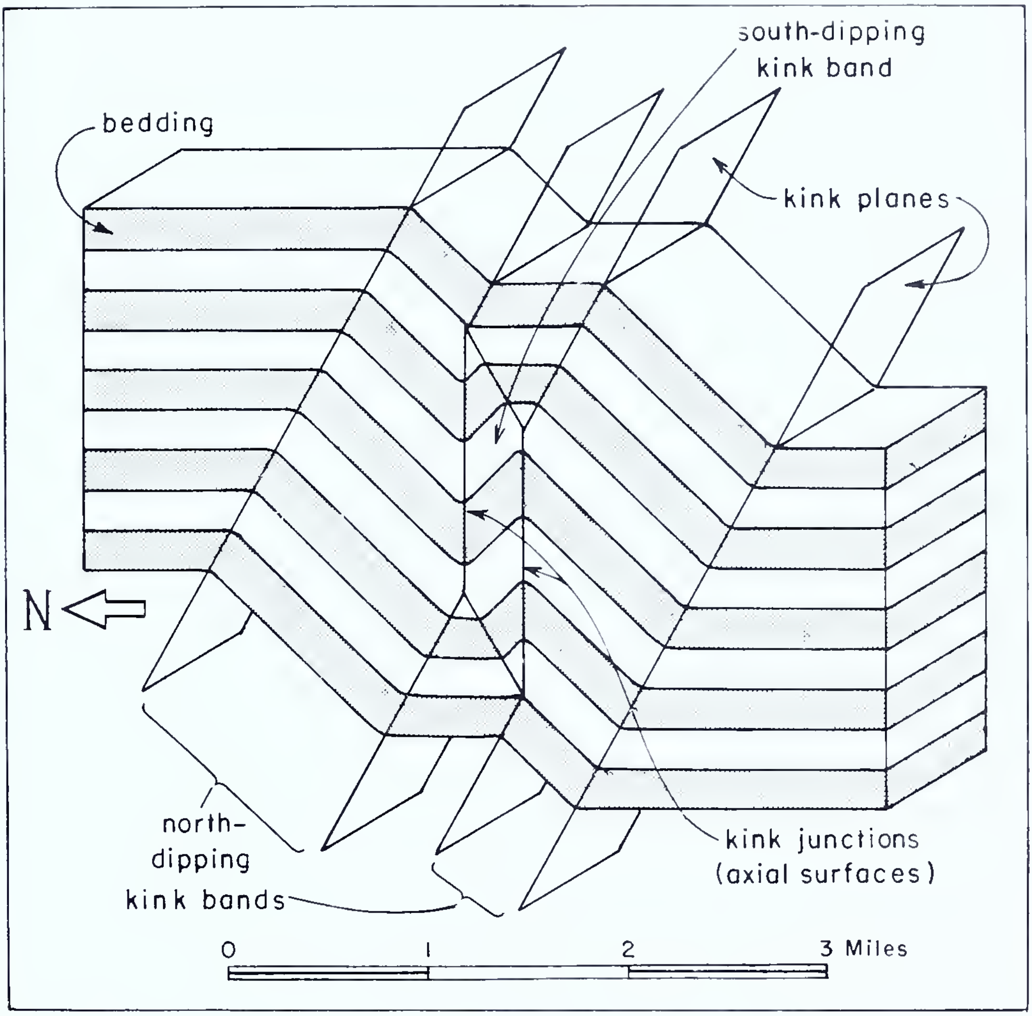


Figure 66. Kink-band model which reproduces all the geometric features of the Cocolamus fold structure: the anticline-syncline fold pair, the conjugate fold, as well as the narrow hinges and planar bedding in the fold limbs.

Faults

Faults in the Millerstown quadrangle occur at all scales, ranging from small dislocations with displacement measured in centimeters to large, mappable offsets with displacements of hundreds of meters. All the faults in the quadrangle can be divided into three categories: 1) wedge (contraction) faults, which lie at a small angle to bedding, and with displacement resulting in lateral shortening and duplication of beds; 2) cross faults, which are normal to the regional fold axis and represent the boundaries of wedge blocks; and 3) extension faults, generally at a large angle to bedding, and with displacement that resulted in lateral exten-

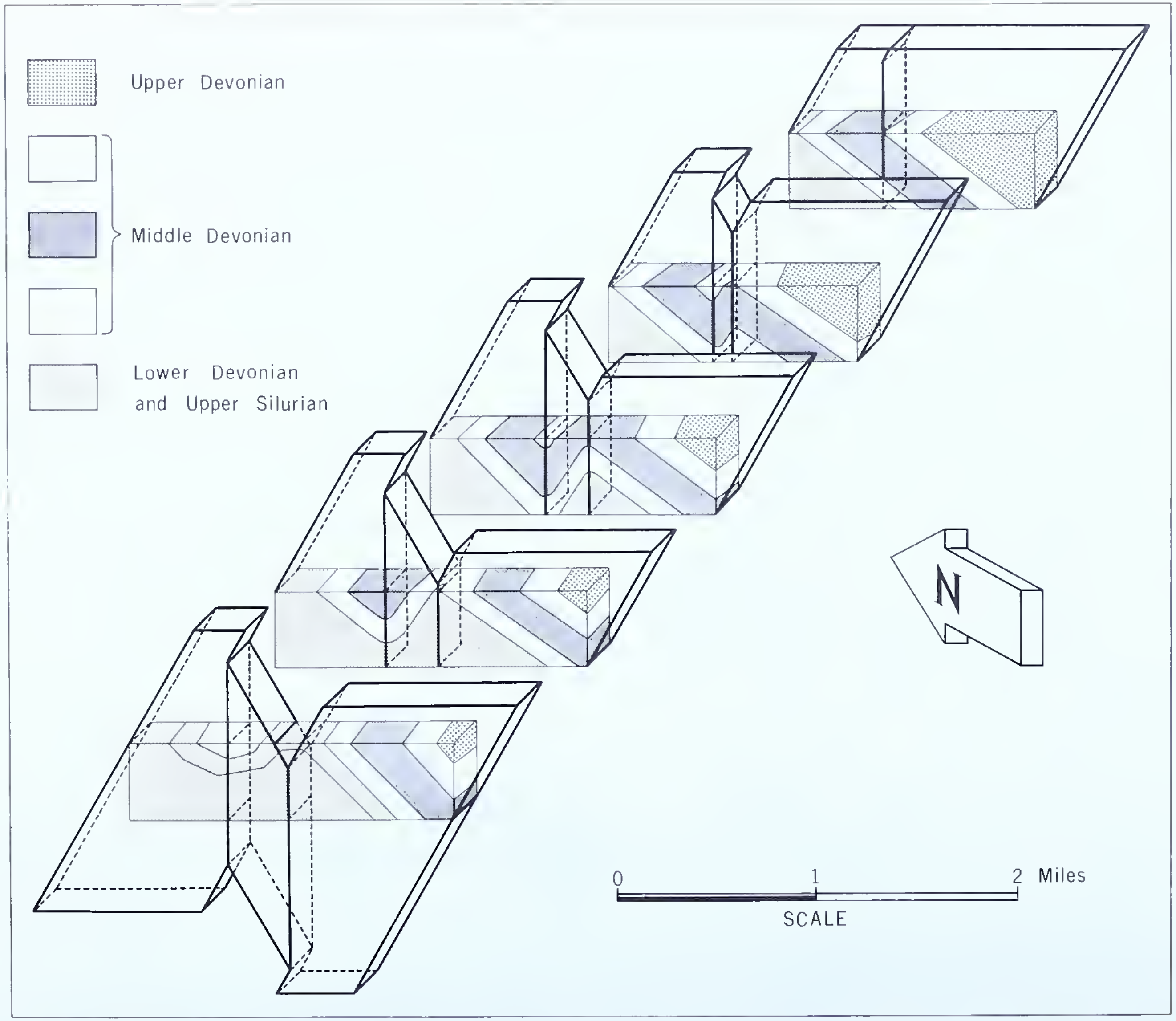


Figure 67. Application of the kink-band model (Figure 66) to the Cocolamus structure. By assuming that the two kink bands are not parallel, but rather converge toward the east, the change in fold structure along trend is completely replicated.

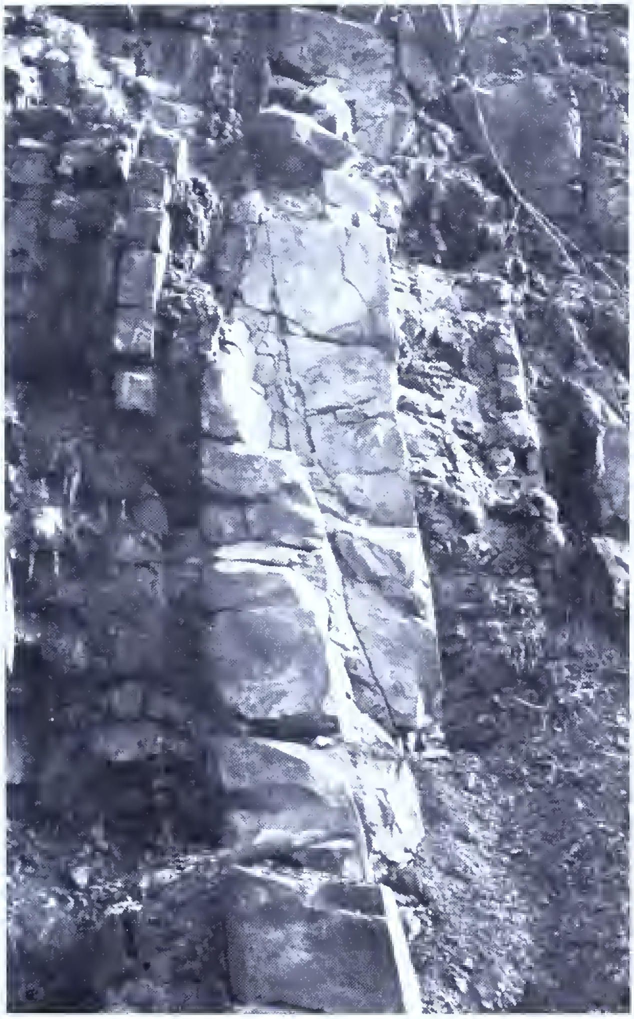


Figure 68. Wedge fault in a vertical quartzite bed, resulting in a partial duplication and lateral (vertical) shortening of the bed. Tuscarora formation in a roadcut along U.S. Interstate 80 at Curtin Gap, 2 miles southeast of the Milesburg Interchange, Centre County.

sion of the beds. All three types of faults are subordinate to the folding—they represent local disruptions in the folding process.

Wedge Faults

Wedge faults occur at a small angle (10 to 30 degrees) to bedding (Figures 68 and 69). The smaller wedge faults transect only one or a few beds, whereas the largest transect hundreds of feet of stratigraphic section. Displacement on these faults represents a lateral shortening of the beds, and a consequent duplication of the faulted beds and thickening of the stratigraphic section. The congruence of slickenside directions on the wedge faults and the adjacent bedding surfaces (Figures 70 and 71) indicates that the wedge-fault movements are kinematically related to the flexural-slip movements. Many of these wedge faults represent a transfer of displacement from one bedding surface to another above or below; in others, displacement on the fault terminates in a fold (Figure 72).

As common as the simple wedge faults (those beginning and terminating in bedding surfaces) are in outcrop, only two of the larger, mappable faults are of this type: the Oriental and Mt. Pleasant Mills faults. The Oriental fault occurs in the Middle Devonian rocks in the east-central part of the quadrangle, on the south side of Turkey Valley. This fault is not exposed, but its presence is indicated by the map patterns which are wider here than elsewhere, by duplication of units, and by the

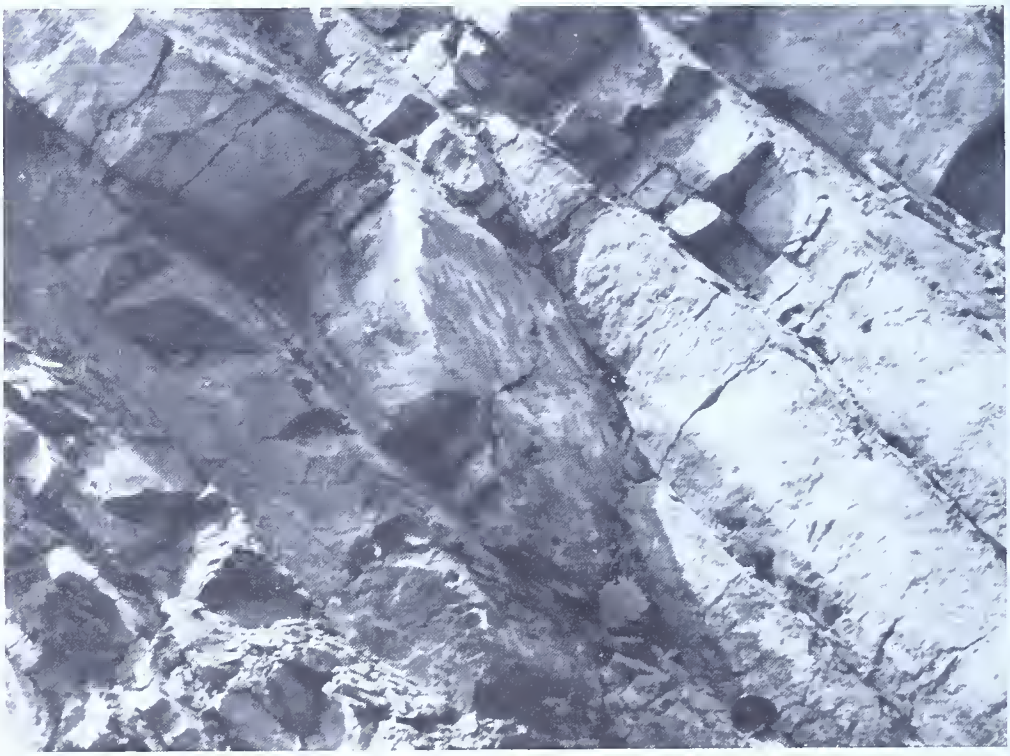


Figure 69. Wedge fault transecting several beds, exhibiting slickensides which show the direction (but not the sense) of displacement. Tuscarora Formation, in a roadcut along U.S. Route 322 at Spruce Mountain, 3 miles northwest of Milroy, Mifflin County. Faint horizontal lines caused by flood damage to negative.

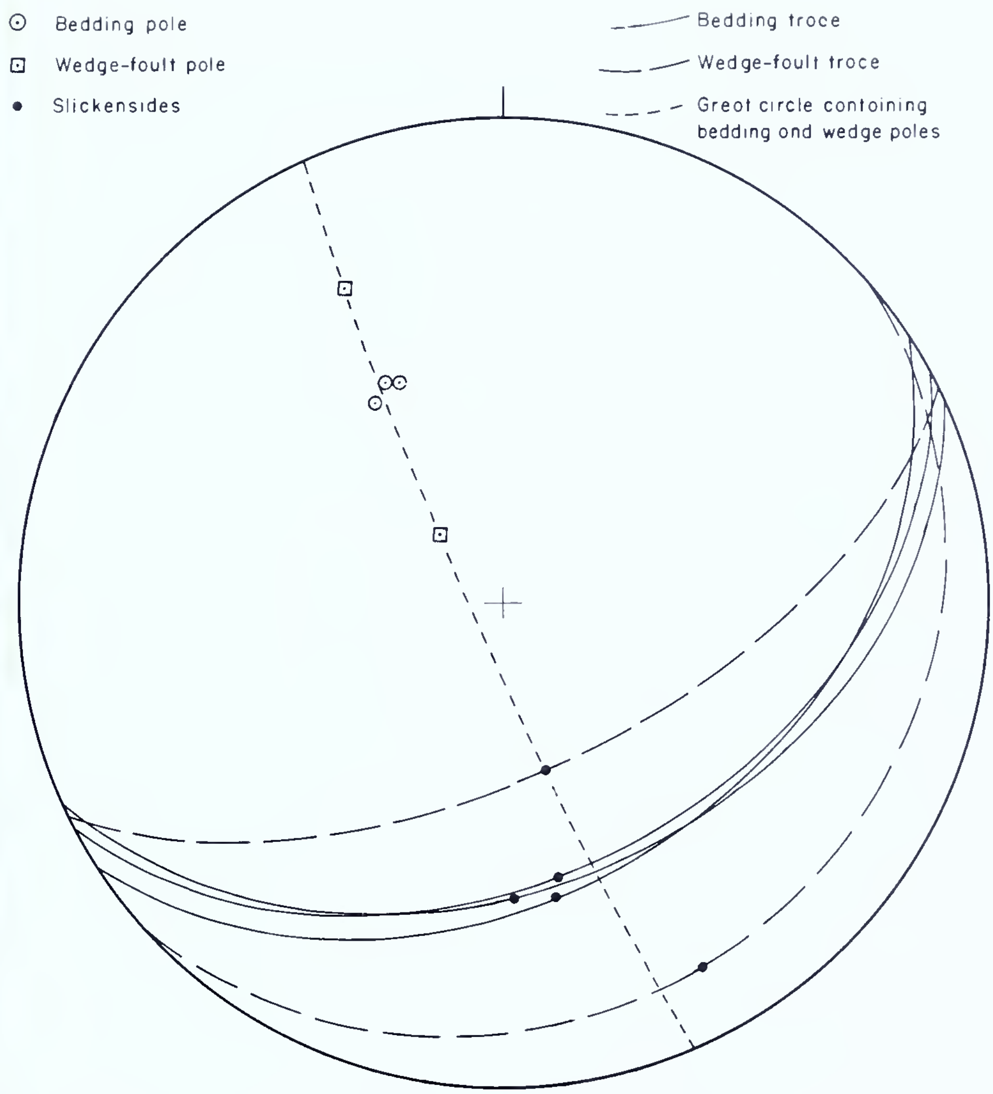


Figure 70. Two wedge faults and adjacent bedding at a single outcrop. Slickensides on the wedge faults are approximately congruent with those on bedding.

lesser dips. On the western end, the fault occurs in the younger rocks and the beds within the overlying Trimmers Rock Formation to the north are "bent" around this area (Figure 73). This indicates that this western end represents the "toe" (leading edge) of the fault. At the eastern end, the fault occurs in older beds, and there is no "bending" of beds in the vicinity, indicating that this end represents the "heel" (trailing edge) of the fault. This pattern does not suggest that the displacement on the fault was east to west, but rather that the present exposure is an oblique

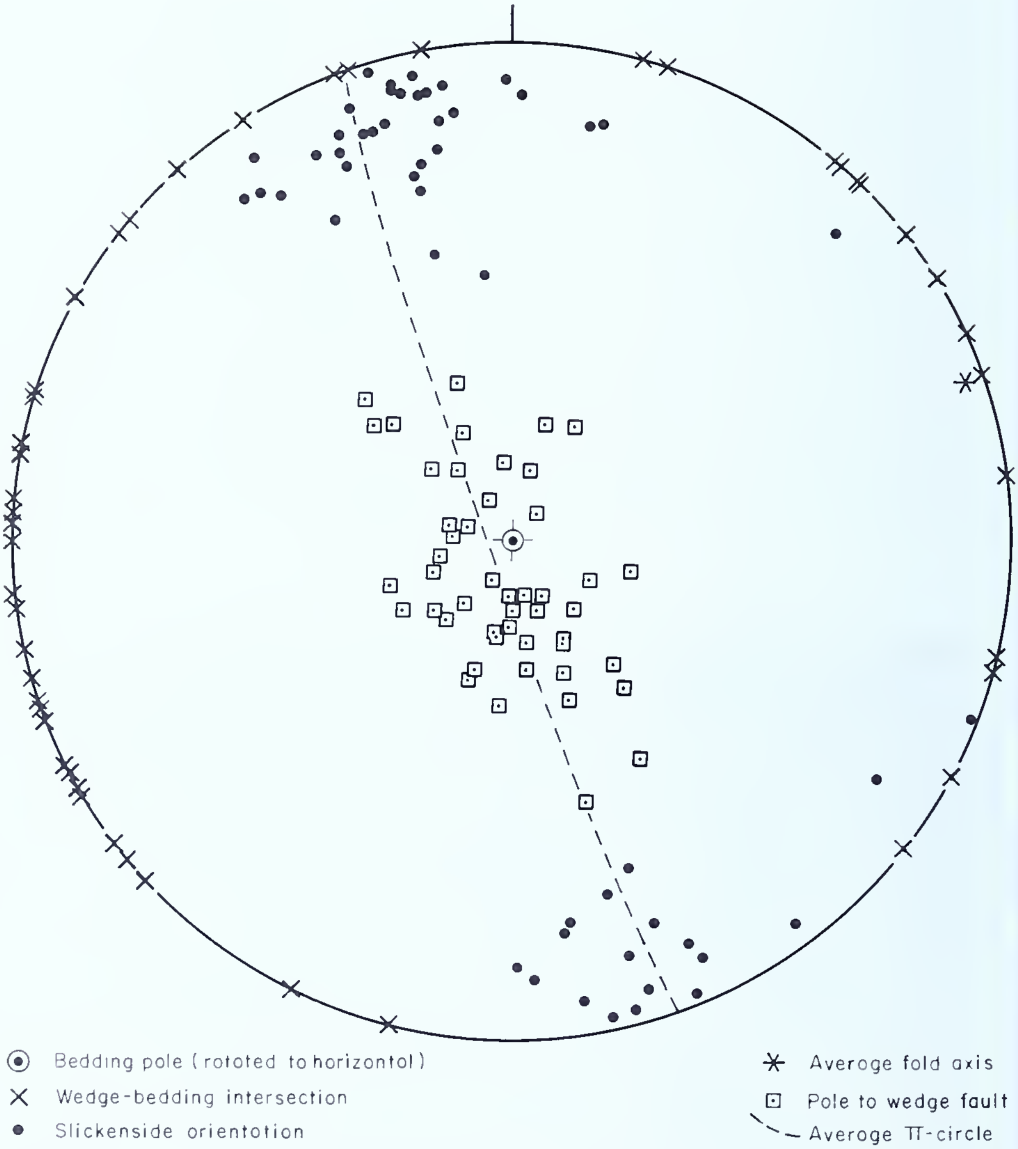


Figure 71. Summary of all the wedge faults and their slickensides measured in the Millerstown quadrangle. The pole of the great circle is the local fold-axis direction. The intersections of wedge faults and bedding were derived, not measured. All data represent bedding rotated to horizontal.

view of the fault—movement on the fault was probably to the south, subnormal to the regional fold axis.

The other large, mappable wedge faults in the quadrangle are associated with folds and with a structural trend change, of which the two

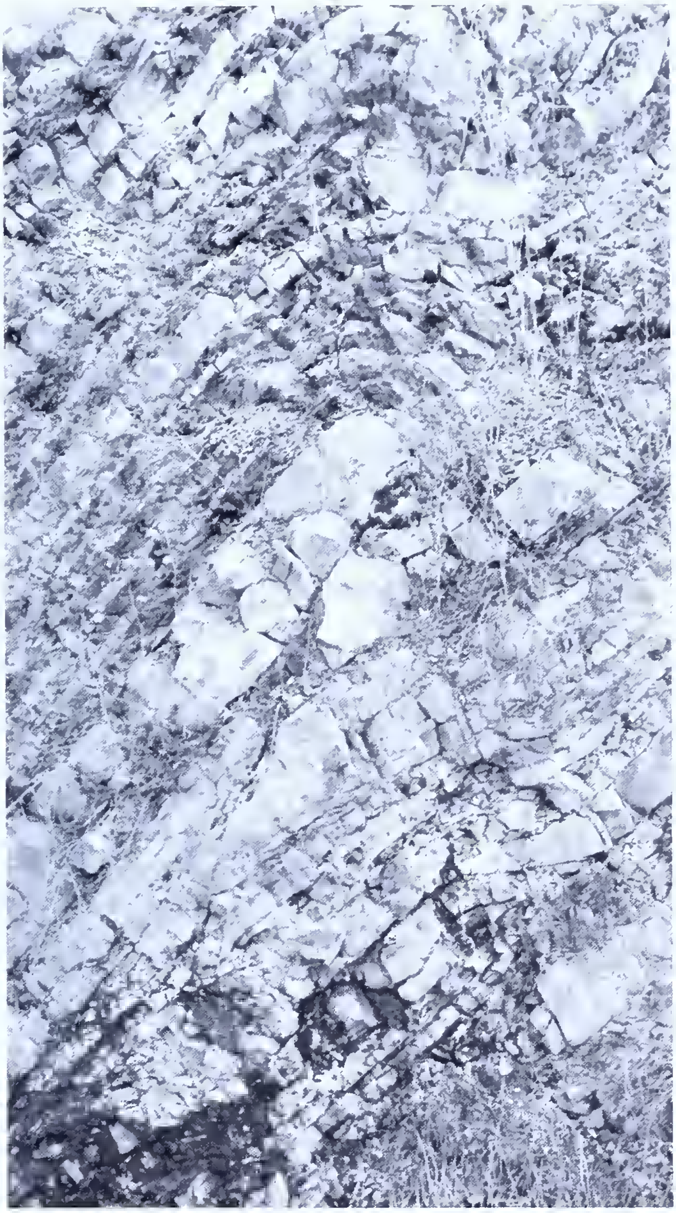


Figure 72. Wedge fault terminating upwards in a kink-band fold. Bald Eagle Formation, in a roadcut along U.S. Route 322, 0.9 mile south of Reedsville, Mifflin County.

Donnally Mills faults are characteristic. These two faults occur in the Middle Devonian rocks in the southwest corner of the quadrangle, duplicating parts of the Mahantango Formation (Plate 1). They extend for 2 miles (3.2 km) to the southwest into the adjacent Loysville quadrangle, where they merge with folds in Silurian and Lower Devonian rocks. The

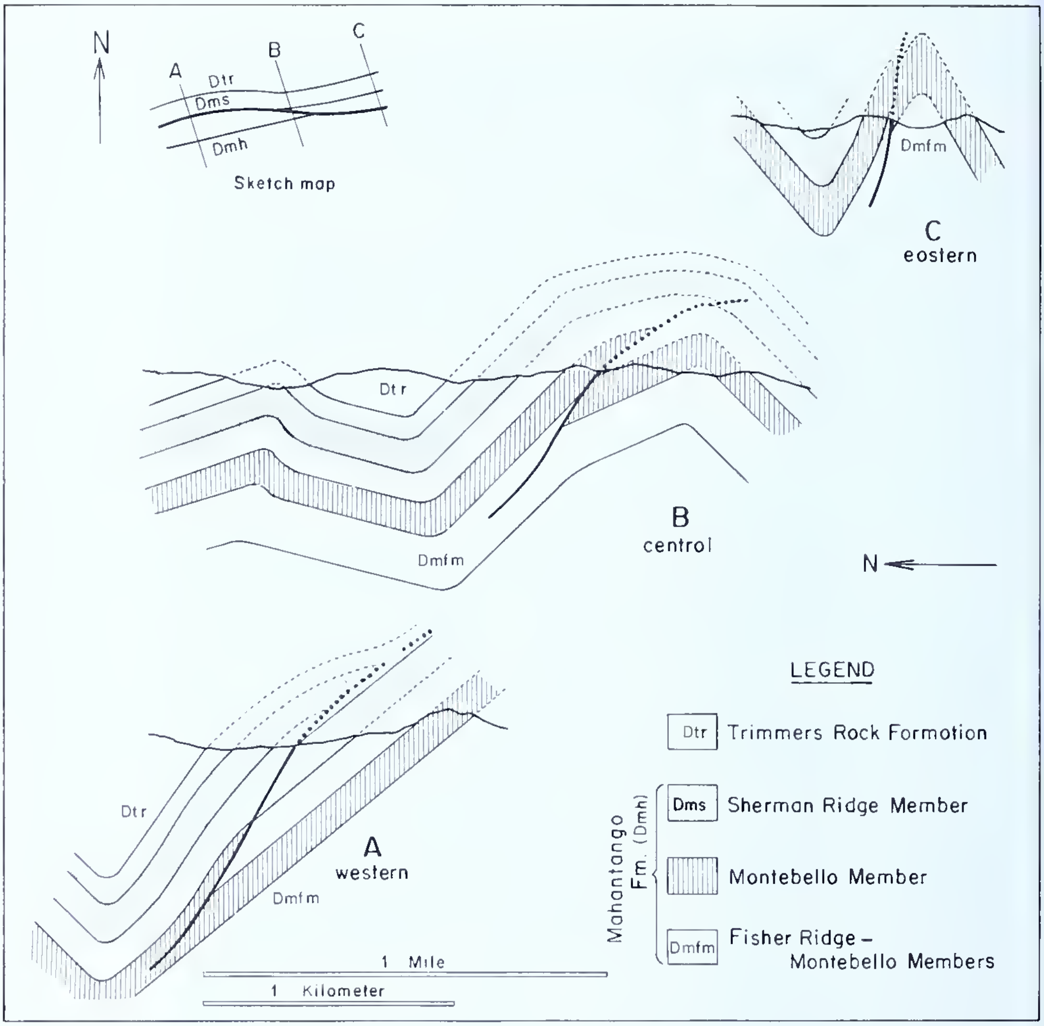


Figure 73. The Oriental fault in the eastern part of the Millerstown quadrangle. As a wedge fault, it originates in the middle of the Mahantango Formation, and terminates in the upper part.

folds trend N53E and plunge gently to the northeast (Miller, 1961). Where these structures pass up section into the Middle Devonian units, the folds give way to faults. East of Donnally Mills, the faults die out and the Mahantango Ridge trends more easterly at N67E. The faults apparently lie above and terminate the folds.

Most wedge faults occur within a single limb, beginning along one bedding surface and terminating along another bedding surface or in a fold. A few wedge faults begin in one fold limb, cross the fold hinge, and terminate in the adjacent limb (Figure 74). Such faults are termed *cross-hinge* faults. In one fold limb, they originate in a bedding surface and transect bedding at the small angle characteristic of wedge faults. In the other limb, they generally transect bedding at a larger angle and do not terminate in a bedding surface. The fold hinge is laterally offset by these faults. Slickensides on the faults indicate that they are congruent with the folding, and thus they represent a local disruption in the folding process. Cross-hinge faults have been observed only in outcrop—no mappable examples have been found in the Millerstown quadrangle.

It should be noticed that most of the faults observed in outcrop occur in sequences of interbedded lithologies of contrasting mechanical properties. Commonly, wedge faults cross only beds of siltstone or sandstone that are surrounded by shales (e.g., Figure 68). Most of the large, mappable faults similarly occur in sequences of interlayered, contrasting lithologies, particularly the Mahantango Formation, which is comprised of cycles of interbedded shales, siltstones, and sandstones. Few faults occur in more lithologically uniform stratigraphic units.

Cross Faults

A number of faults (with slickensides) are subperpendicular to the regional fold-axis direction, and are thus termed *cross faults*. Slickensides

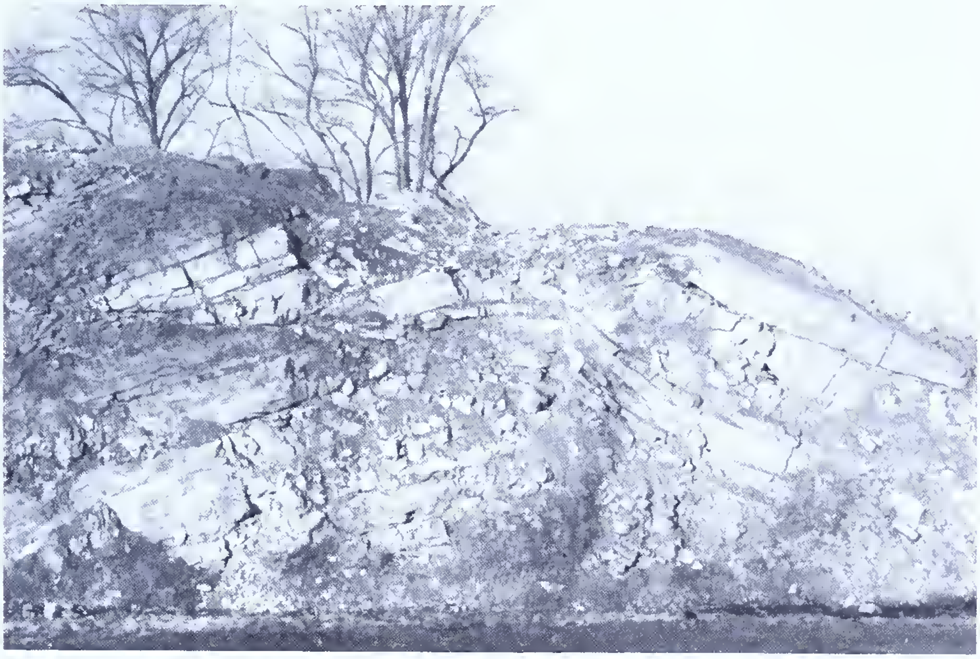


Figure 74. Cross-hinge fault, offsetting the upper part of the fold hinge approximately 15 feet to the left. Mahantango Formation, U.S. Route 22-322, 2.7 miles north of Amity Hall, Perry County.

on the cross faults are invariably at a small angle to the bedding trace (Figure 75), an angle similar to that between wedge faults and bedding (Figure 76). This suggests that the cross faults are intimately related to both the folding and wedge faulting. As such, they probably represent lateral terminations of wedge blocks (Figure 77).

As with cross-hinge faults, cross faults have been observed only in outcrop. No cross faults sufficiently large to be mapped have been found in the Millerstown quadrangle.

Extension Faults

In a very few exposures, faults occur at a large angle to bedding, generally 60 or more degrees. In contrast with the wedge faults, displacement on the extension fault is such that the beds have been laterally extended. A number of these are inclined to each other and mutually offset each other (Figure 78), indicating they are conjugate (developed at the

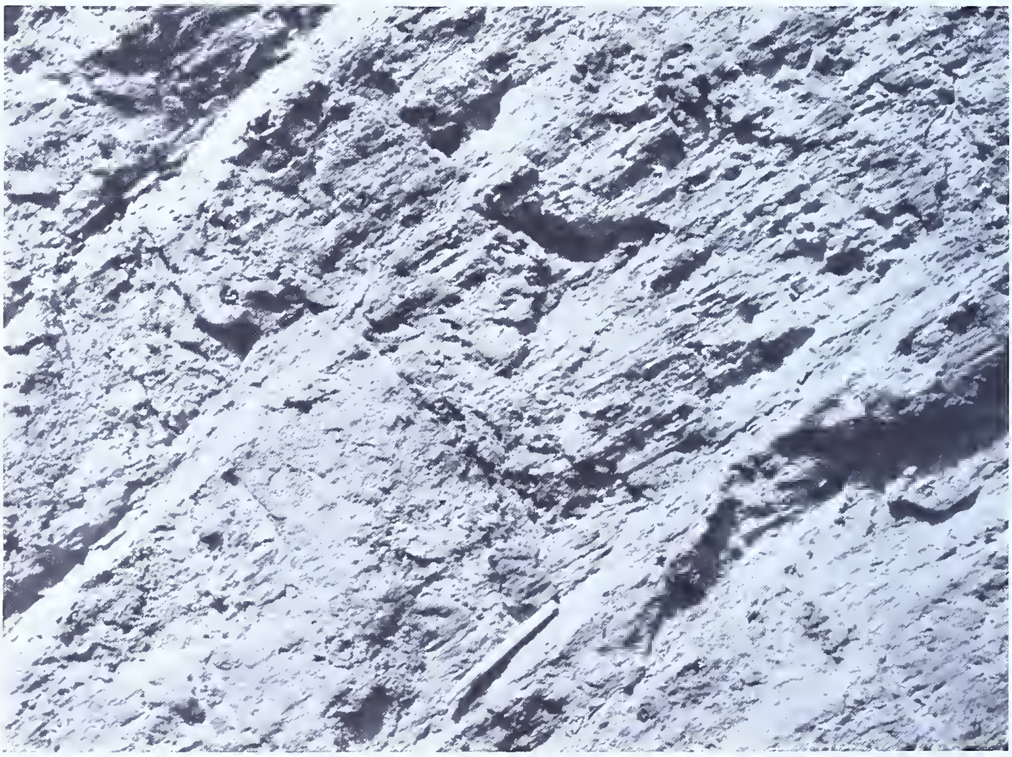


Figure 75. Slickensides on a minor cross fault. Bedding trace is indicated by the pen. Mahantango Formation, along the Penn Central Railroad cut on the east bank of the Susquehanna River, 2.8 miles southwest of Sunbury, Northumberland County.

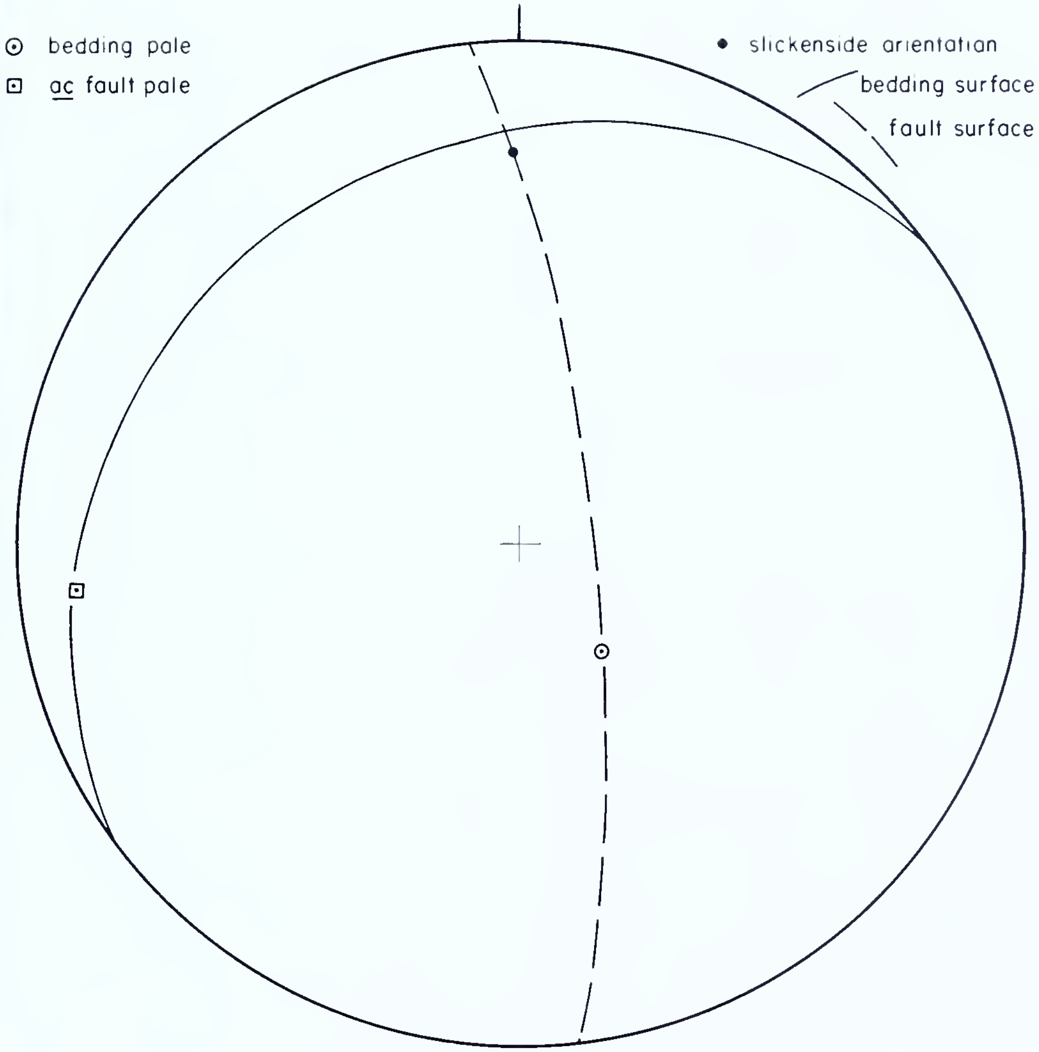


Figure 76. Slickensides on a cross fault, illustrating the small angle between the slickensides and the bedding–cross-fault intersection.

same time under a single stress system). Their mutual intersection, and their intersections with bedding, parallel the fold-axis direction (Figure 79). They usually occur in the hinges of folds, and they offset wedge faults as well as slickensided bedding. Their geometric congruence with the folds indicates that they were part of the folding process, but their offsetting of all other structures indicates that they occurred late in the folding.

Extension faults have been observed only in outcrop. No such faults of sufficient size to be mappable have been observed in the Millerstown quadrangle.

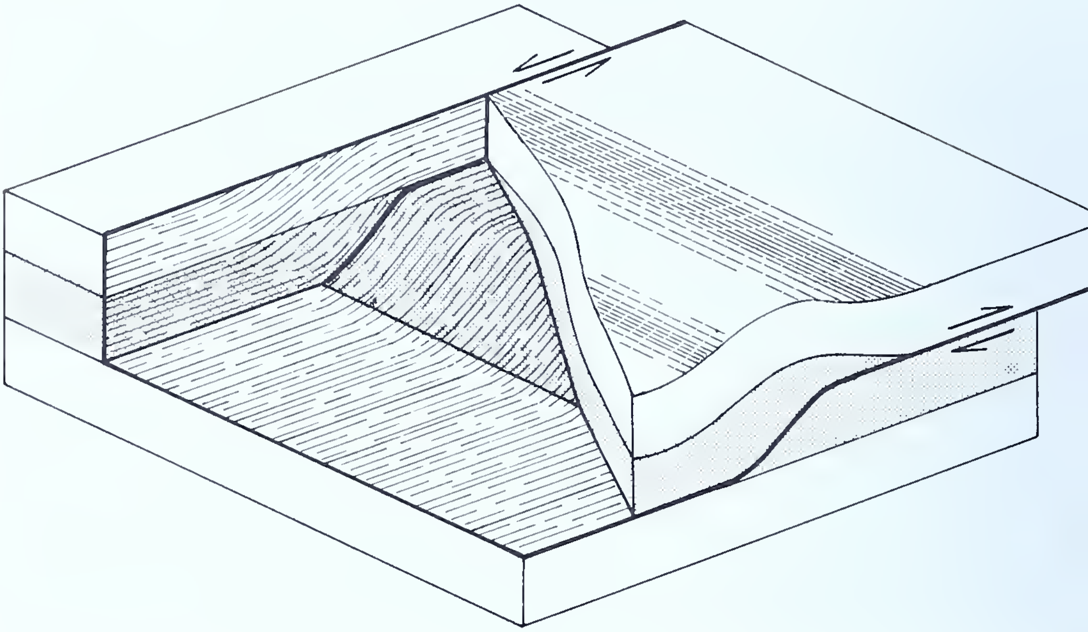


Figure 77. Wedge block terminated laterally by a cross fault. Lines on bedding and fault surfaces represent slickenside directions.

Fractures (Joints)

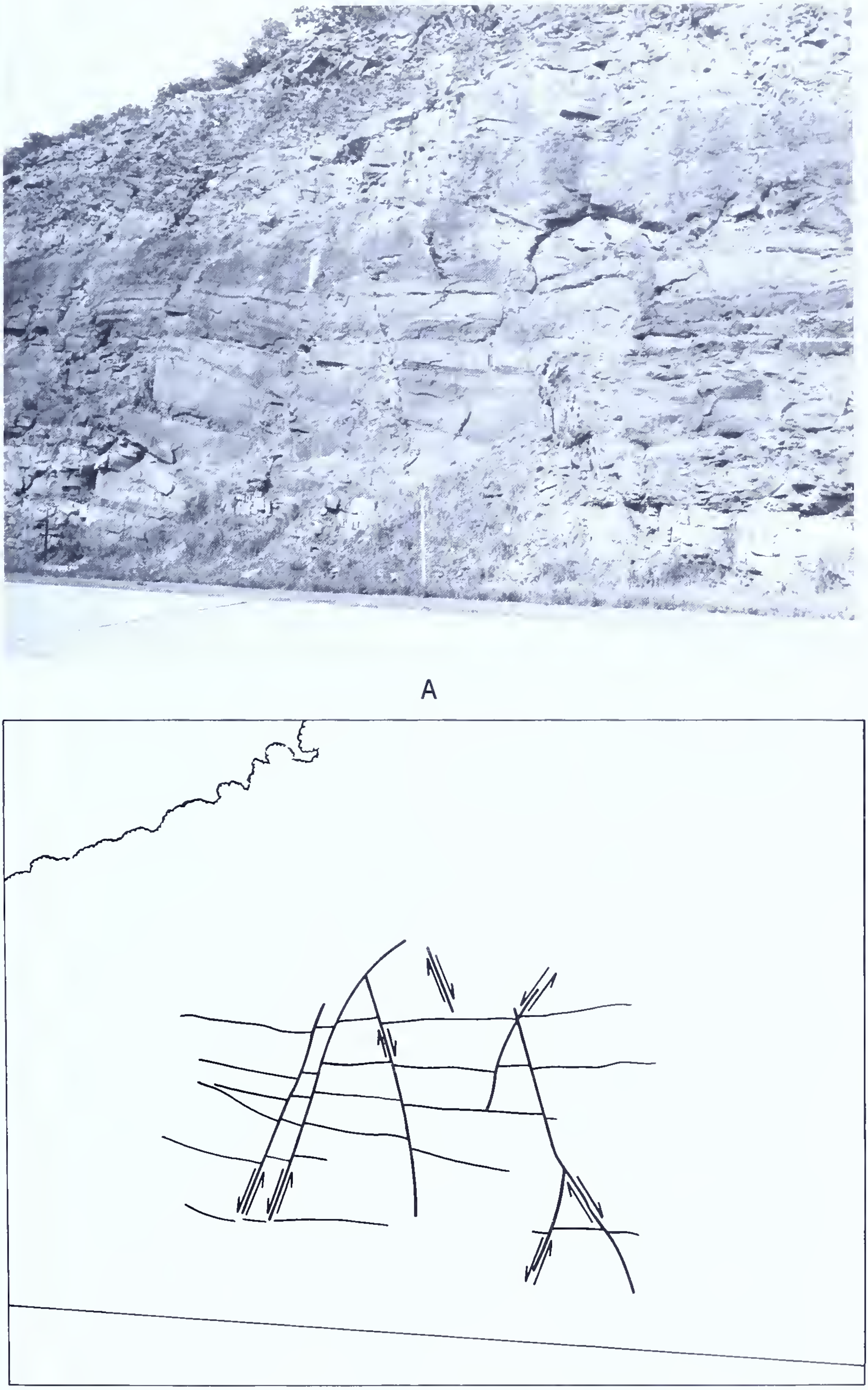
The term fracture, as used in this report, refers to those ubiquitous surfaces in the rock along which rupture has occurred. Excluded from this category are the faults described in the previous section. That is, fractures are those ruptures along which very little or no discernible movement has occurred, and which do not have slickensides on them.

The fractures observed in the Millerstown quadrangle can be divided into two broad categories: irregular and planar.

The irregular fractures vary from smoothly undulatory to very angularly irregular (Figure 80). They are generally not very extensive, and are often restricted to a single layer. Because of the irregularity of their

Figure 78. A. Conjugate extension faults in the hinge of the Buffalo-Berry syncline. Catskill Formation (Duncannon Member) in a roadcut on U.S. Route 22-322 (southbound lane), 3.9 miles south-southeast of Millerstown, Perry County.

B. Sketch of conjugate extension faults in the Catskill exposures of Buffalo-Berry syncline, shown in A.


A
B

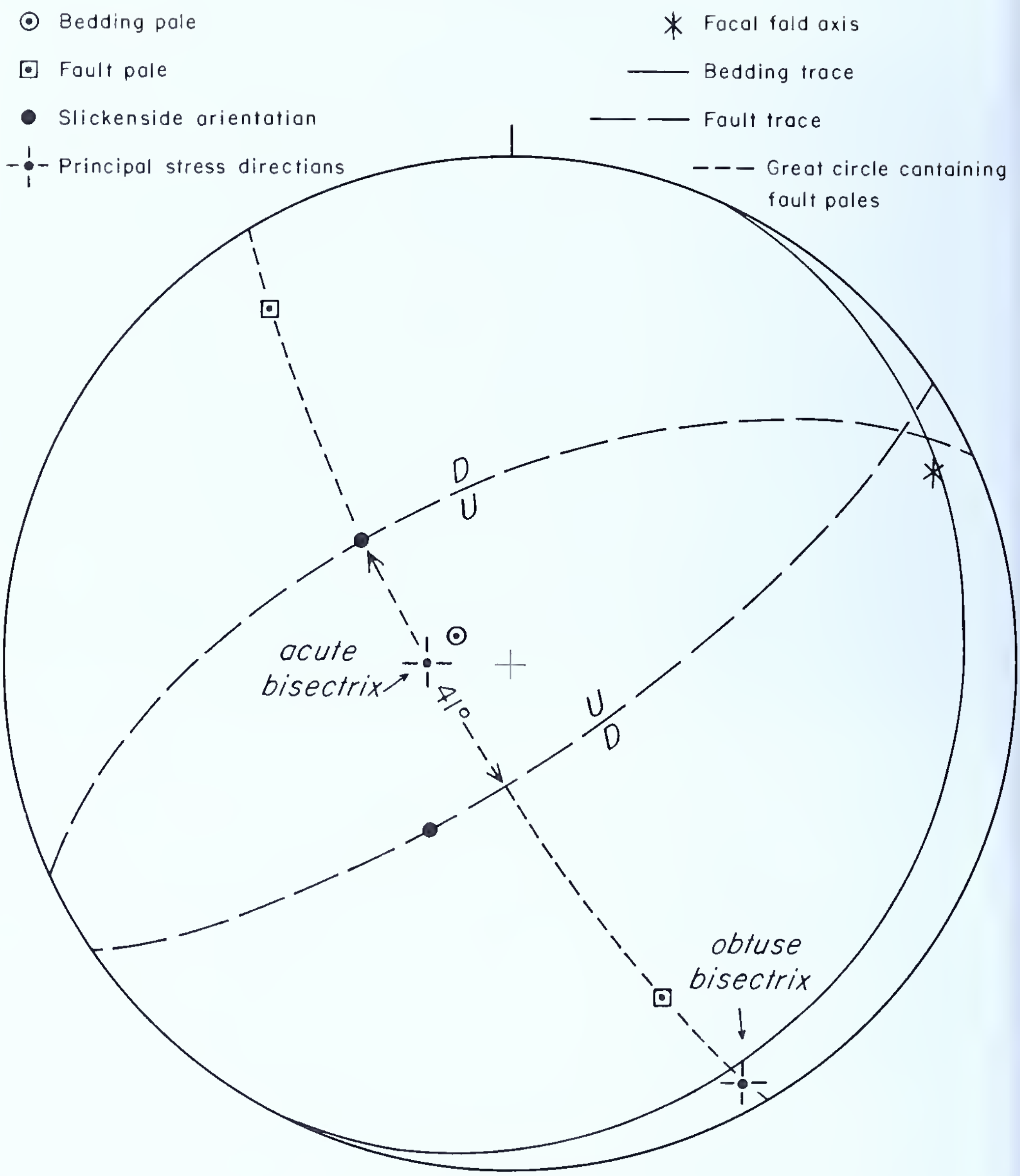


Figure 79. Two extension faults in the hinge of the Buffalo-Berry syncline. The intersection of the faults is close to the fold axis, and the slickensides on the faults are subnormal to both.

surfaces, their orientations are difficult to estimate and measure. Thus, no orientation data were collected on fractures of this category.

More commonly, fractures in the rock are quite planar and smooth (Figure 81); all of the fracture data on the engineering map (Plate 5) were measured on fractures of this planar category. The following analysis is based on data from 109 fractures from 45 outcrops in the vicinity of

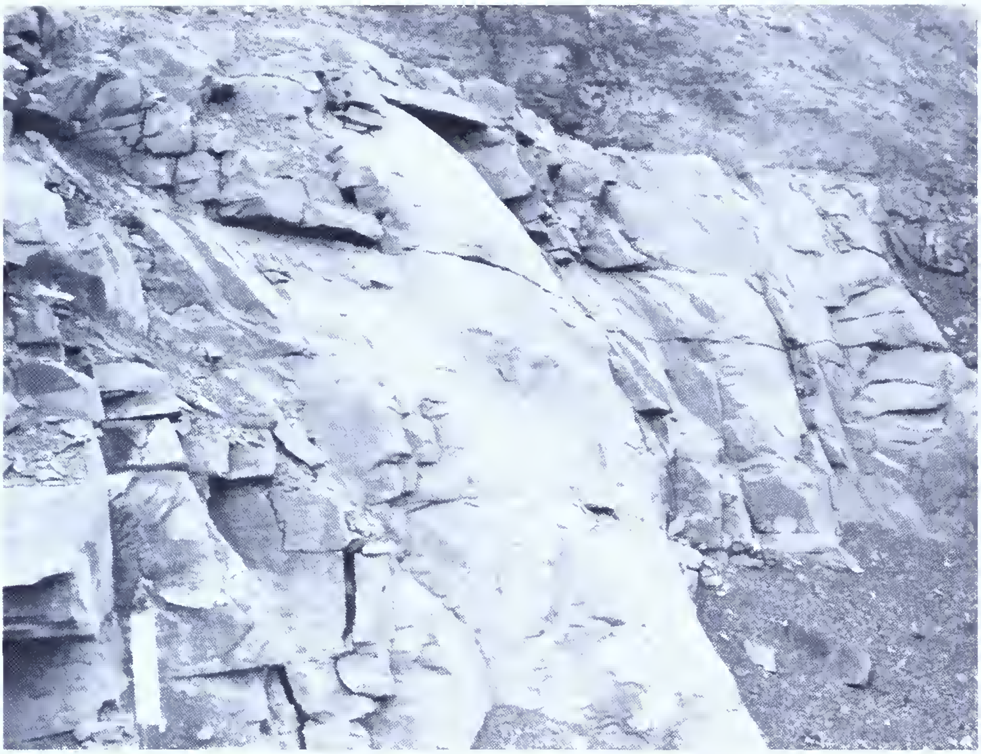


Figure 80. Curved and irregular fractures. Catskill Formation in a roadcut on U.S. Route 22-322 (southbound lane), 3.8 miles south-southeast of Millerstown, Perry County.

Millerstown near the hinge of the Tuscarora anticlinorium. This limited area was selected to avoid mixing data from areas of different structural trend.

Figure 82 illustrates the density distribution of the fractures in three dimensions. The clustering of fracture poles in the northeast and southwest quadrant perimeters represents fractures that are oriented normal to the local fold-axis direction. These fractures are called dip fractures because their line of intersection with bedding is subparallel to the dip direction of the bed. The other significant clustering of fractures occurs as a broad band from the northwest to the southeast quadrant. These strike fractures (their intersections with bedding are subparallel to the strike of bedding) are arranged subnormal to the dip fractures. The alignment of this orthogonal fracture pattern with the fold geometry indicates that the folds and fractures are genetically related.

In order to examine the relationship of the fractures to the bedding in which they occur, the data of Figure 82 were replotted as follows: for each outcrop, bedding was rotated about its strike to horizontal, and the fractures in that outcrop were rotated a corresponding angle about the

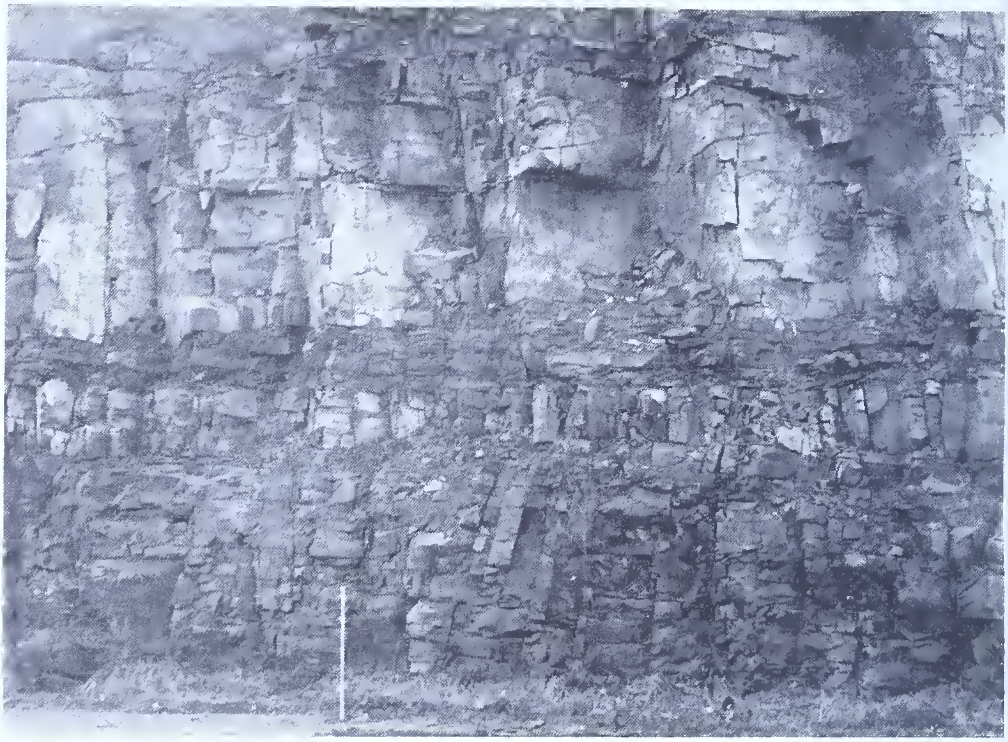


Figure 81. Planar fractures. Catskill Formation (Duncannon Member) in a roadcut on U.S. Route 22-322 (southbound lane), 4 miles south-southeast of Millerstown, Perry County.

same axis. In effect, the contribution of bedding dip was removed from the fracture orientation data. The same orthogonal pattern appears as before, but instead of a broad-band distribution of the strike fractures, they are clustered near the perimeters of the northwest and southeast quadrants (Figure 83). This indicates that both the dip fractures and the strike fractures are subnormal (70 to 90 degrees) to bedding.

The considerable dispersion of the data in the clusters in Figure 83 does not reflect a random distribution within broad limits. Examination of the data from single outcrops indicates that both the dip fractures and the strike fractures occur in pairs and even triplets; i.e., all of the dip fractures (or strike fractures) in a single outcrop fall into one of two or three well-defined sets. Deviation of a single fracture from the mean orientation of a given set is small. The angle between the sets is approximately 20 degrees, ranging from 15 to 35 degrees (Figure 84).

Cleavage

In most of the rocks in the Millerstown quadrangle, cleavage is not particularly well formed. It is best developed in some shales (particularly

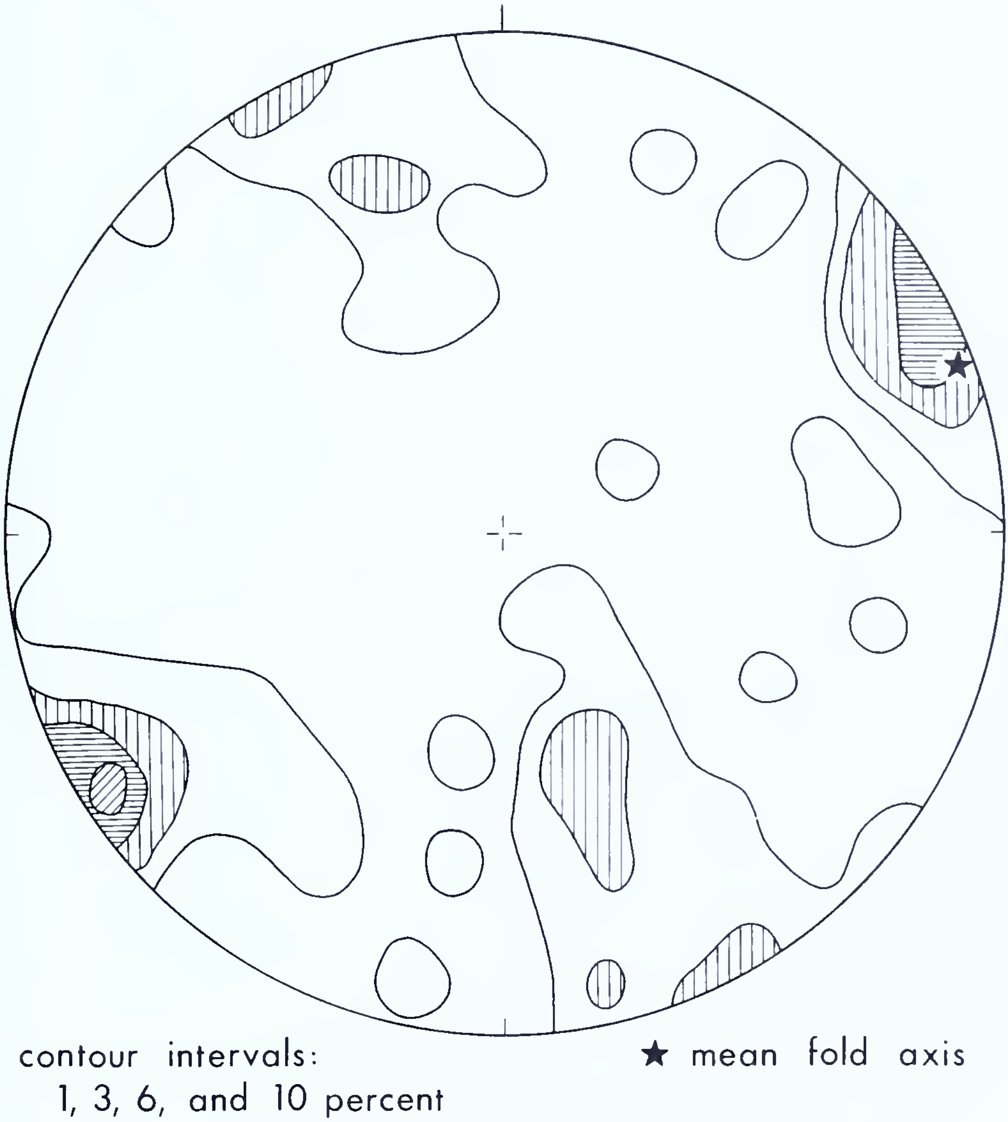


Figure 82. Orientations of 109 fracture sets measured in the vicinity of Millerstown.

the Bloomsburg, to a much lesser extent the Catskill, Juniata, Rose Hill, Trimmers Rock, and Mauch Chunk Formations) and in some argillaceous limestones (particularly the Keyser Formation, and to a much lesser extent the Tonoloway and Wills Creek Formations).

It is a fracture cleavage, consisting of sets of closely spaced (1/2 to 3 inches, 1 to 8 cm) partings separated by relatively undeformed, noncleaved rock (microlithons). The cleavage originated by pressure solution in all the rock types. Material (either calcite or quartz, depending on the rock type) was removed by solution along the cleavage partings, with a consequent enrichment of clay and carbon (Nickelsen, 1972).

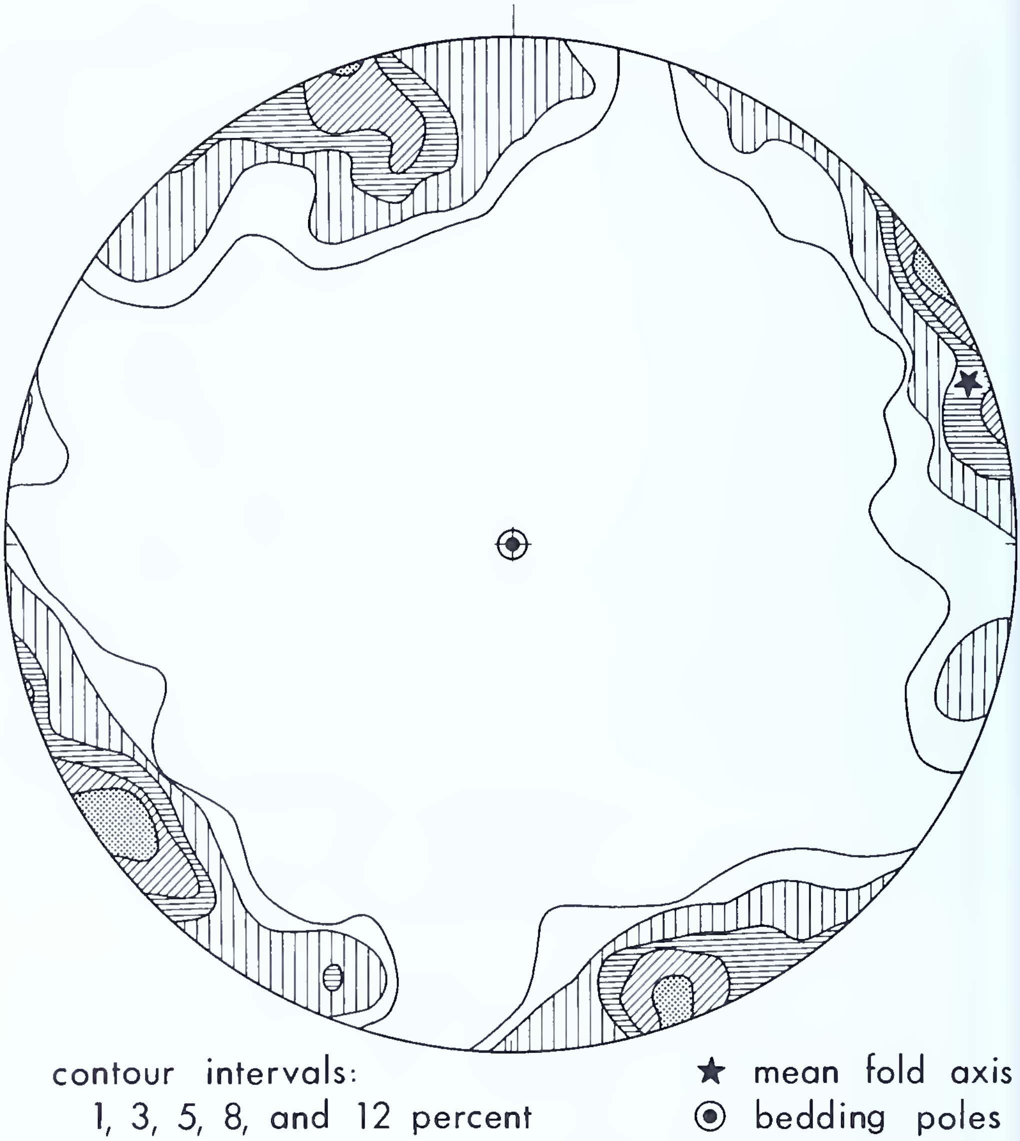


Figure 83. The same 109 fracture sets as in Figure 82. For each locality, bedding has been rotated to horizontal, and each of the fracture poles has been rotated correspondingly.

The nature of the cleavage varies as a function of rock type, principally in spacing, width, and continuity of the cleavage partings. In the Bloomsburg shales, the cleavage is pervasive, but the individual partings are very thin, fairly close together, and quite discontinuous, imparting to the rock a distinctive hackly fracture. In the Keyser, the partings are wider (consisting of many thin partings grouped together into a cleavage zone up to 1/4 inch, 1/2 cm, wide), fairly continuous (at least across

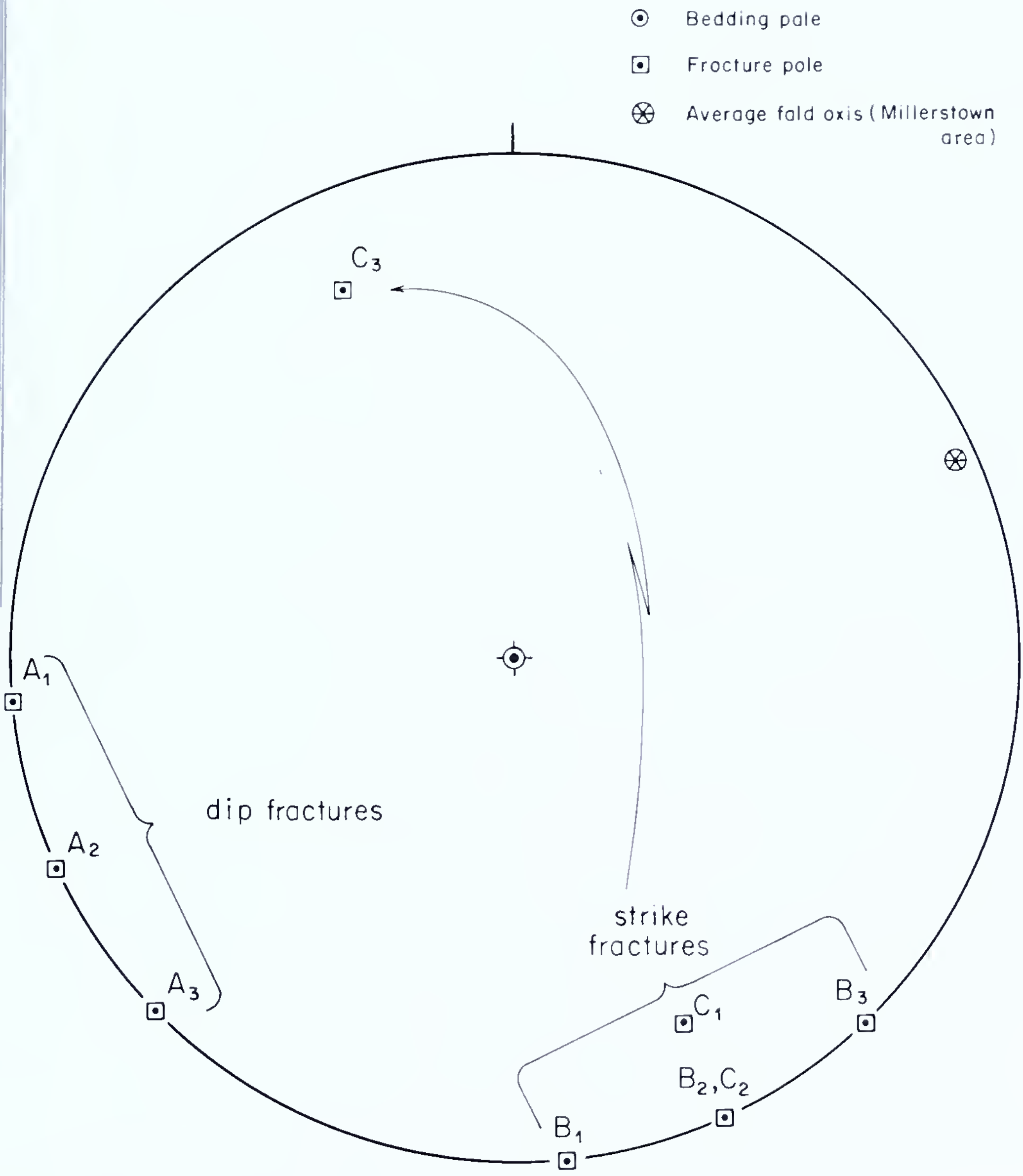


Figure 84. Summary of fracture orientations. The dip fractures occur in one of three sets (A1, A2, A3); the strike fractures occur in one of five sets (B1, B2, B3, and C1, C2, C3; the B2 set is equivalent to the C2 set).

single beds, and frequently across several beds), and further apart (2 to 5 inches, 5 to 12 cm), as in Figure 85. In particular locations, as in the hinge of a few small folds in the Tonoloway Formation, the cleavage is very well developed; the partings are narrow and well defined, very continuous across bedding (to the point of almost obliterating bedding), and rather closely spaced (1/32 to 1 inch, .07 to 2.5 cm), as in Figure 86.

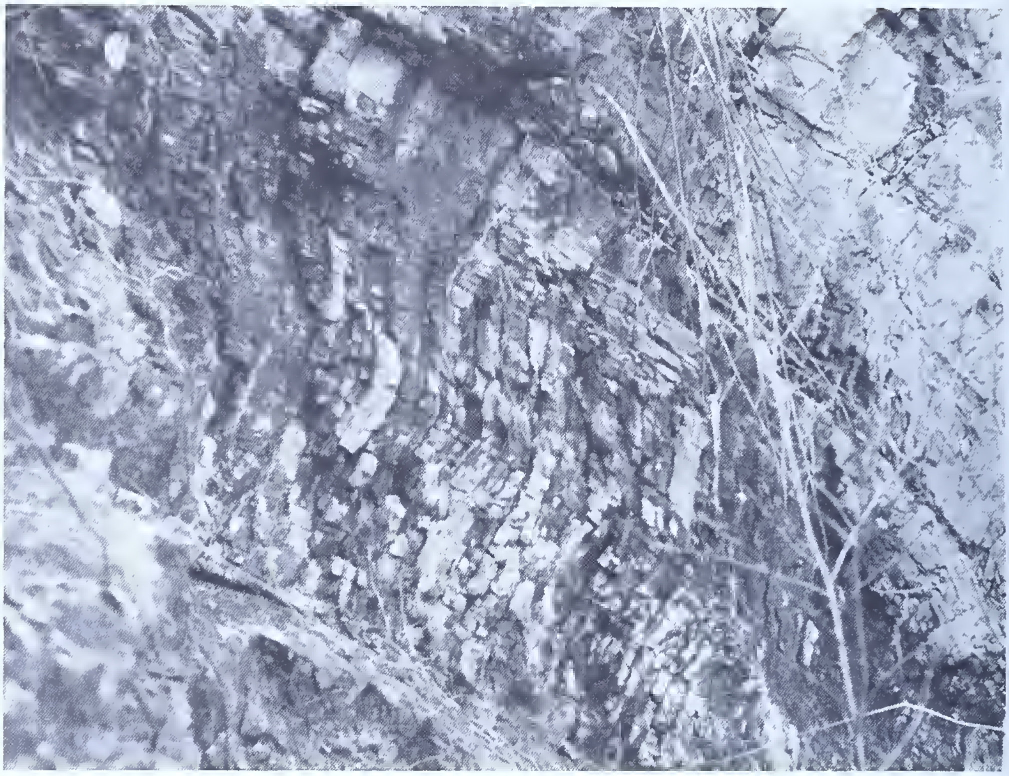


Figure 85. Fracture cleavage in the Keyser Formation, in a quarry on Lime Ridge in Snyder County, 2.4 miles northwest of Richfield, Juniata County.

In those outcrops where the cleavage is not well developed, the partings show no obvious enrichment of clay and carbon. These partings are easily mistaken for a closely spaced fracture set. In some localities, there is also a suggestion of two cleavages present, intersecting each other at an angle of 30 to 45 degrees.

The cleavage appears to have developed during folding because of the parallelism of the bedding-cleavage intersections with the fold axes (Figure 87). Whereas some of the cleavage is a true axial-plane cleavage (as in Figure 86), much of the other cleavage "fans" the fold; in the fold hinge the cleavage is normal to bedding, but in the fold limbs it dips away from the cleavage in the hinge. This fanning of cleavage may represent an orthogonal (to bedding) cleavage developed early in the folding that was subsequently rotated externally away from the axial plane (internally toward the axial plane). The true axial-plane cleavage probably reflects extensive solution activity in the later stages of folding, and was not subsequently rotated.

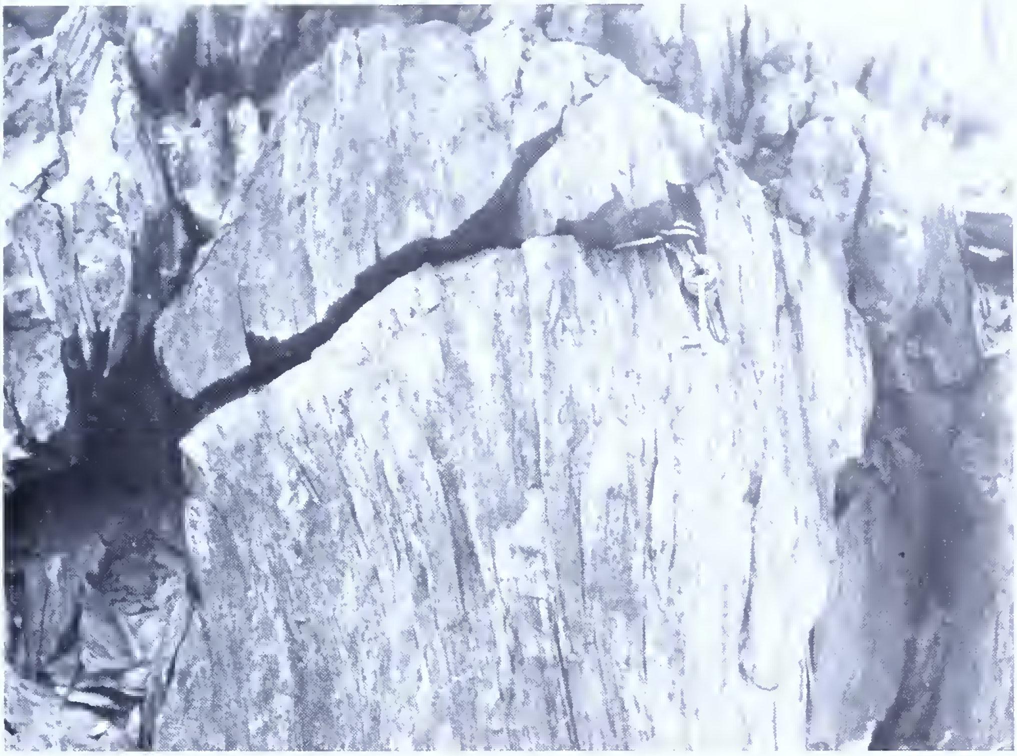


Figure 86. Cleavage in the hinge of a small fold in the Tonoloway Formation, in a small quarry on Lime Ridge in Snyder County, 2.4 miles northwest of Richfield, Juniata County. The subvertical cleavage transects the faint anticlinal bedding. The cleavage is refracted in a 1-inch-thick layer on the right side of the photograph.

LARGE STRUCTURES ON THE GEOLOGIC MAP

Introduction

It has been demonstrated (see sections on simple folds and wedge faults) that the largest structures in the quadrangle are geometrically similar to the small structures observable in outcrop. The largest folds possess narrow hinges and relatively constant bed orientation in the limbs, as do the smallest folds. Kink-band (flexural-slip) folding was the dominant deformational process; wedge faulting was a subordinate process. Because of the wide range of fold sizes, the simplicity of the largest folds is somewhat obscured by the presence of smaller folds. It seems appropriate, therefore, to describe the larger, mappable structures, and to demonstrate how they relate to each other.

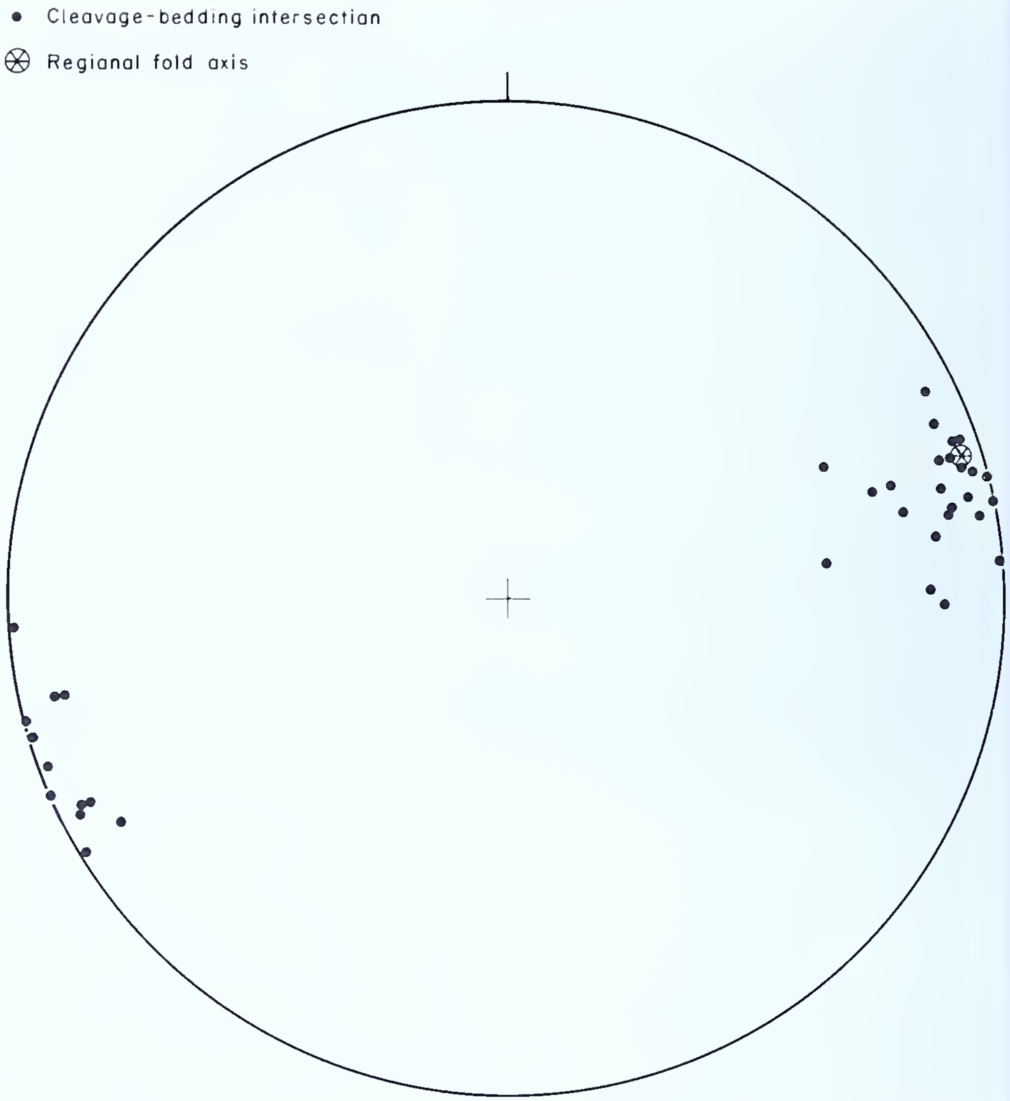


Figure 87. Cleavage-bedding intersections in the Millerstown quadrangle.

Two anticlinoria and two synclinoria cross the Millerstown quadrangle—each will be discussed separately beginning with the southernmost. Although an anticlinorium and an adjacent synclinorium share a common limb (and thus lesser structures in that limb belong to both major folds), it seems simpler to discuss each lesser structure in the context of the major fold hinge to which it is closest.

Buffalo-Berry Synclinorium

The axial trace of the Buffalo-Berry synclinorium crosses the quadrangle from the south edge to the east edge, trending N71E. The synclinorium plunges in this direction at 10 degrees; the youngest rocks exposed in the hinge are the Mauch Chunk Formation. The attitude of the axial surface is approximately subvertical. The bedding tends to be steeper in the south limb than in the north limb, suggesting that the fold is probably inclined to the northwest.

The synclinorium is fairly simple with few folds and faults in the limbs. The dip of bedding in the limbs is moderate to steep and quite uniform throughout each limb. There is not the smoothly progressive increase in dip away from the hinge that is characteristic of concentric folds. Rather, the overall geometry is similar to that of the smaller kink-band folds seen in outcrop.

A fault-fold structure (Buffalo Mountain) of third-order size occurs 1 3/4 miles (2.8 km) north of the synclinorium hinge along the east edge of the quadrangle and in the Millersburg quadrangle to the east (Figure 88). The bifurcated ridges of Pocono rocks (see Plate 1) are separated by the fault. The southern ridge is an anticline, plunging eastward at approximately 11 degrees and terminating as a topographic ridge at the river. The northern ridge continues eastward from the Susquehanna River into the Millersburg quadrangle as a homoclinal ridge. The fault passes from Catskill rocks in the west through the Pocono Formation into Mauch Chunk rocks to the east. Because no evidence of the fault was found in the Catskill rocks north of the mountain scree, it is concluded that this edge of the fault parallels bedding somewhere in the Duncannon Member. It also appears to parallel bedding in the Mauch Chunk rocks to the east and thus is inferred to be a very large wedge fault (Figure 89). The anticlinal Buffalo Mountain fold that is associated with the fault occurs only in the rocks above the fault and represents folding of the overlying beds during the faulting. This fault-fold structure is oblique to the trend of Buffalo Mountain, plunging 11° N72E, virtually identical to the plunge of the synclinorium. Because of this eastward plunge, the lower part of the structure (the trailing edge of the fault) is exposed in the west, and the upper part (the toe) in the east.

In the midst of the Catskill outcrop belt in the north limb of the synclinorium, a 1000-foot-wide (305 m) zone of very gently southeast dipping rocks extends for 2.5 miles (4 km) east and west from Centerville (Figure 88). This zone has the geometry of a subvertical kink band, but the sense of rotation in the rocks is unusual. In every other kink band in this synclinorium, the rocks have steepened and overturned. In the Centerville kink band, they appear to have been rotated back towards horizontal. On the east side of the Susquehanna River, a zone of overturned beds in the Pocono Formation dips to the north at about 20 degrees (Hoskins, 1967), possessing a kink-band geometry. Because of the opposite senses of rotation, these two kink bands seem to be a conjugate pair.

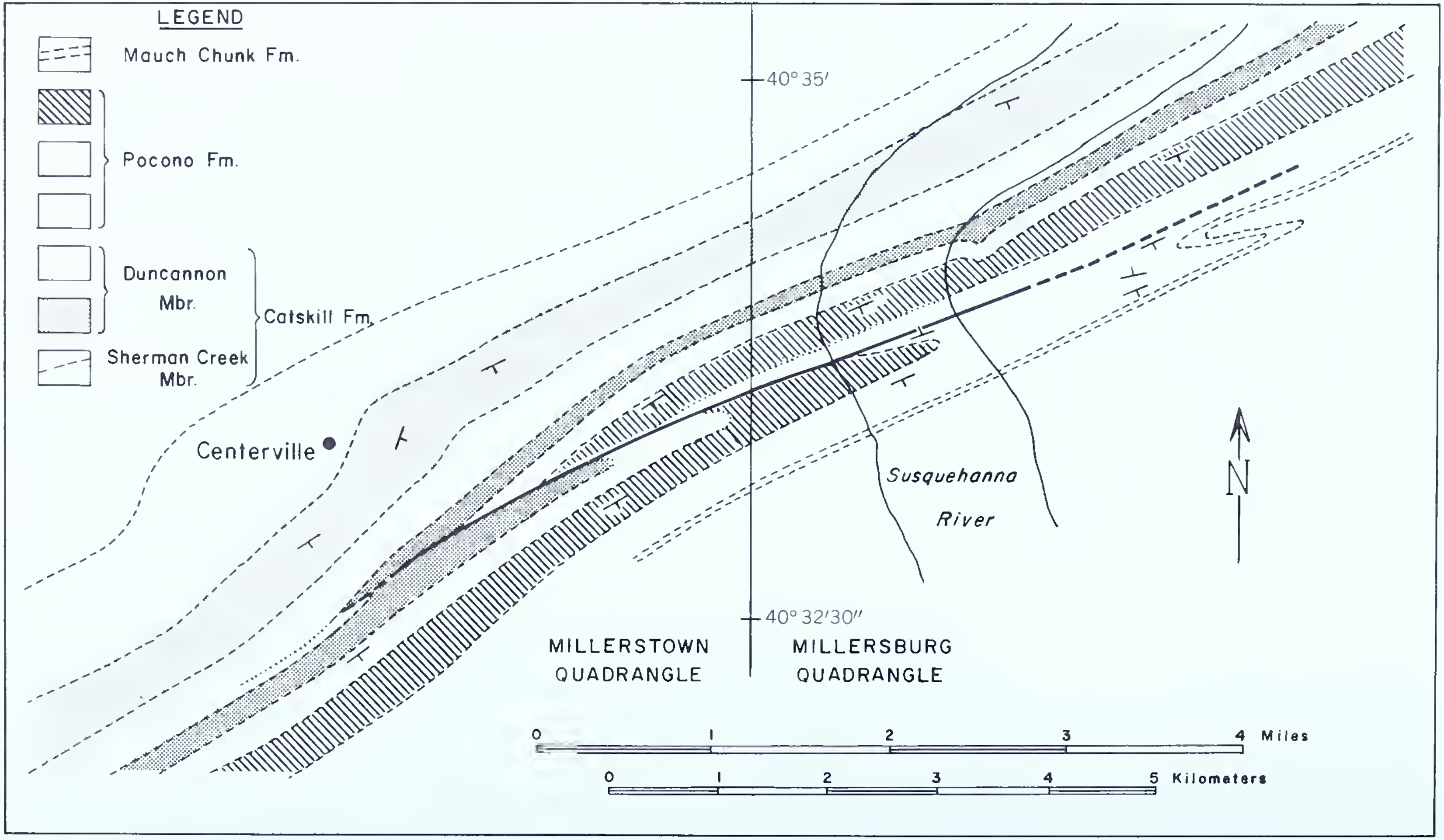


Figure 88. Map of the Buffalo Mountain fault-fold structure. Geology in the Millersburg quadrangle by Hoskins (in prep.).

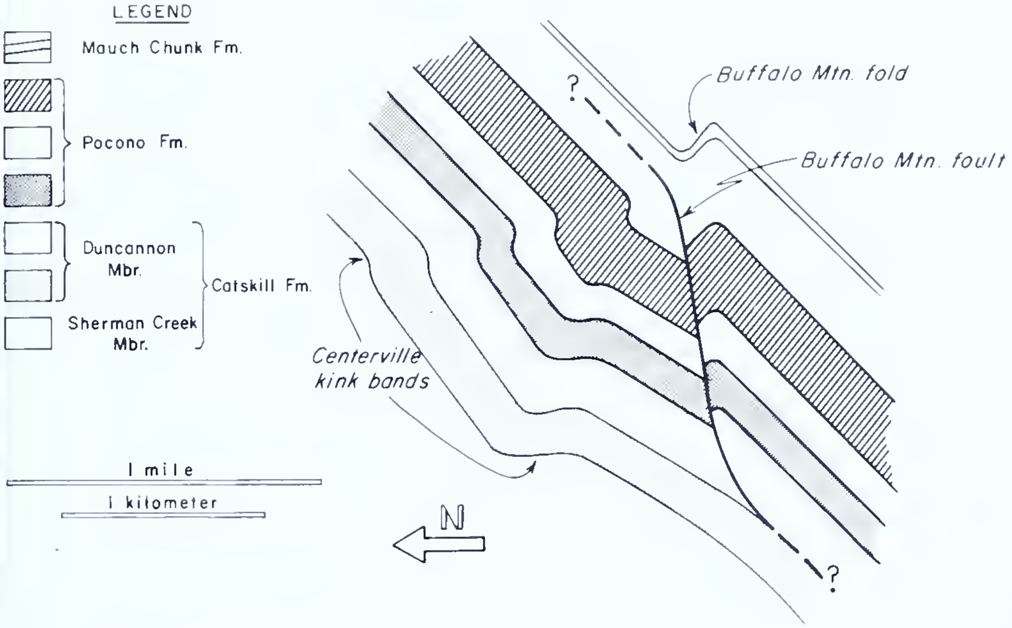


Figure 89. Cross section inferred from the map in Figure 88. The Buffalo Mountain fault appears to be a large wedge fault, with a fold developed in the overriding block. The Centerville kink bands are a conjugate set developed in the overridden block.

The geographic location of this conjugate kink-band structure is noteworthy. It is not directly connected to the Buffalo Mountain fault structure, but occurs 1 mile (1.6 km) north of it. Also, it divides a terrain of steeply dipping rocks to the north and east from moderately dipping rocks to the south. Its geometry is similar in trend and orientation to the Buffalo Mountain fault-fold structure. Thus, these kink bands appear to be related to the Buffalo Mountain structure, as a local distortion that resulted from faulting and folding to the south.

Tuscarora Anticlinorium

The Tuscarora anticlinorium lies to the north of the Buffalo-Berry synclinorium, occupying most of the southern half of the Millerstown quadrangle (and sharing a common limb with that synclinorium).

The hinge of the anticlinorium trends N66E in the western portion of the quadrangle and N75E in the eastern portion, a sizable change in direction for such a short distance along trend. The change is not gradual, but rather abrupt, occurring in the vicinity of Slaughterback Hill. The anticlinorium plunges an average of 4 degrees across the quadrangle, 6 degrees less than that of the Buffalo-Berry synclinorium. The oldest rocks exposed in the hinge are the Silurian Tuscarora Formation.

The area of abrupt change in trend is the same area in which the anticlinorium hinge undergoes significant changes in its cross-sectional profile. West of the quadrangle, at the culmination of the anticlinorium at Run Gap (north of Ickesburg in the Loysville quadrangle), the anticline has planar limbs and a narrow hinge (Figure 90). At the Juniata River, the hinge is considerably wider and appears concentric (see Figure 53). Eastward, at Cocolamus Creek, the fold profile is conjugate with a broad area (interlimb) of gently northeastward dipping beds between the hinges. Further to the east, at the hinges of the conjugate fold, small anticlines appear and increase in amplitude toward Nekoda. At Nekoda, the conjugate geometry of the hinge is replaced by two anticlines and an intervening syncline. Eastward toward the eastern boundary of the quadrangle, the southern anticline diminishes in size and vanishes in the flank of the northern anticline. At the eastern boundary of the quadrangle, there is again a simple anticlinal geometry similar to that at Run Gap, 22 miles (35 km) to the west.

This change of hinge structure is a consequence of a change in the trend of the kink bands comprising the fold. North of Slaughterback Hill, the rocks in the northern limb of the anticlinorium have been rotated about an axis trending N77E, whereas in the southern limb, the axis of rotation was N68E. The eastward convergence of these two different trends causes the fold to plunge to the east, and local strain inhomogeneities resulting from this change in trend caused the development of the third-order folds in the hinge of the anticlinorium.

The south limb of the Tuscarora anticlinorium has been discussed in part in the preceding section on the Buffalo-Berry synclinorium. The only other significant structures in the south limb are the Donnally Mills fault, which was described in the section on wedge faults, and the Wildcat fault-fold structure.

The Wildcat fault, in Wildcat Ridge 0.5 mile (0.8 km) south of Millerstown, begins in the Fisher Ridge Member of the Mahantango Formation and crosses up section to the east, terminating in the Sherman Ridge Member. An anticline-syncline fold pair north of the fault in older rocks plunges gently eastward, and terminates against the fault. In these respects the Wildcat structure is similar to the Donnally Mills fault-fold structure. The principal difference is the presence in the Wildcat structure of a small anticline and syncline in the rocks above the fault east of the Juniata River. This fold pair is not a continuation of the fold pair below (north of) the fault (and transected by the fault); it originates and increases in amplitude to the east before flattening out and losing

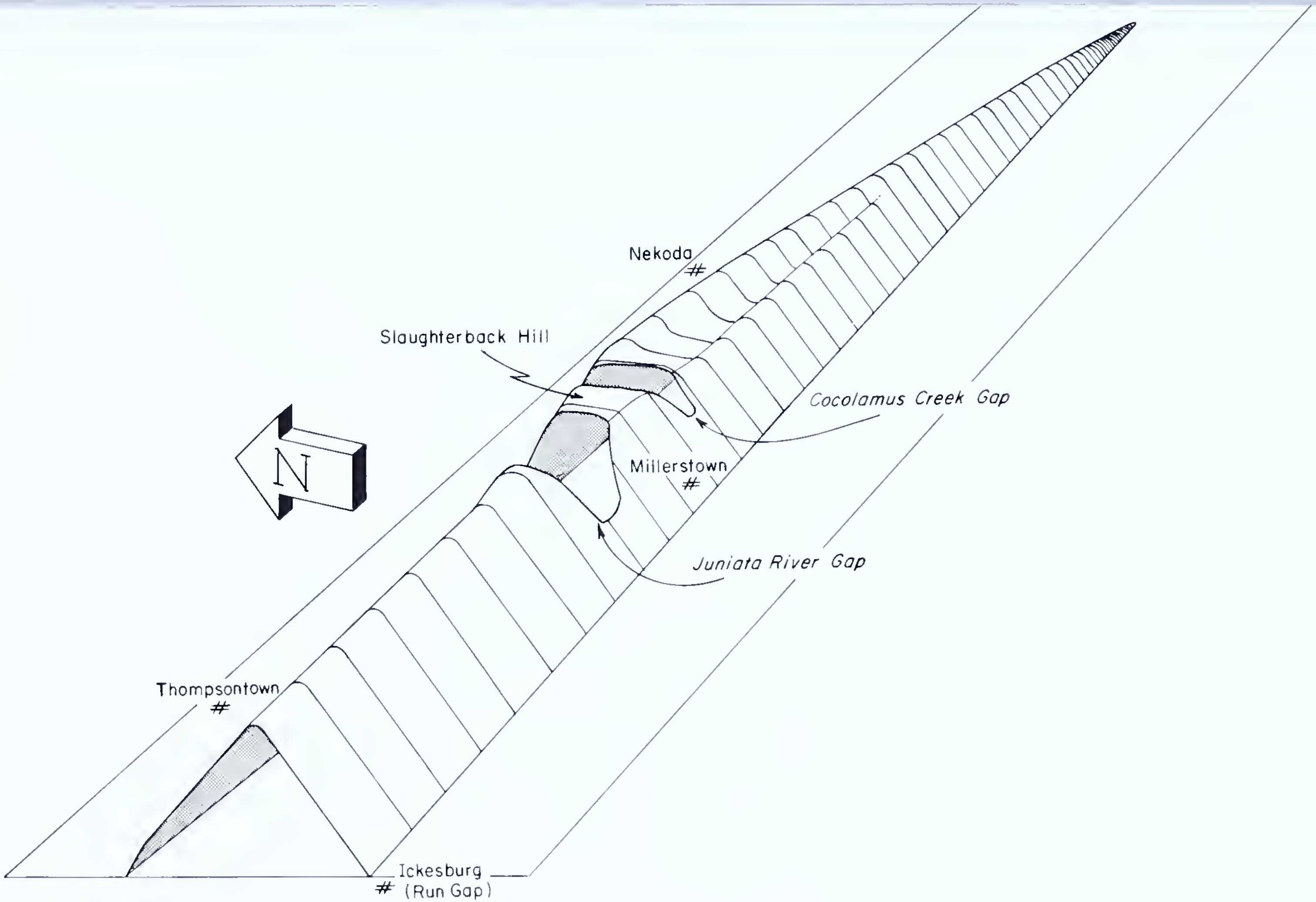


Figure 90. Configuration of the top of the Keefer Formation along the Tuscarora anticline. The complexities of the fold geometry between Millerstown and Nekoda are related to the change in trend of the north limb of the anticline.

definition. The Wildcat fault was apparently a consequence of the underlying folds, whereas the overlying folds represent local deformation within the overriding block. The two sets of folds were therefore somewhat independently developed.

Compared to the relative simplicity of the south limb, the north limb of the Tuscarora anticlinorium is complex. From the area north of Thompsontown that is underlain by Lower and Middle Devonian rocks, a complex of structures extends across the quadrangle with great changes in cross-sectional profile. West of Delaware Creek and east of Cocolamus Creek, the folds are relatively simple and open. Between the two creeks, these folds are transected by three wedge faults, resulting in duplications of cycles within the Mahantango Formation (similarities among these cycles preclude a definitive unraveling of the structures). Apparently, the amount of horizontal shortening required in this area during the regional deformation was greater than could be accommodated by simple folding. As a consequence, wedge faulting was a major supplementary deformational process here.

North of these faulted folds, the Shelley's Ridge anticline is a relatively simple conjugate fold, with a subsidiary fold in the crest that trends N45E (25 degrees different from that of the main anticline). North of White Oak Hollow, another subsidiary anticline is developed on the south hinge of the conjugate fold. This subsidiary fold parallels the main anticline and persists for at least 2 miles (3.2 km) to the east where it apparently diminishes in size and vanishes. North of Wardville, the Shelley's Ridge anticline is again a simple conjugate fold.

In the area of Cocolamus Creek all three faults diminish in displacement to the east and vanish. In addition, the three anticlines (Shelley's Ridge, and the two faulted anticlines, Dimsville and Cranes Run) decrease in amplitude, becoming two very open, simple folds. This change in structure along trend represents a significant decrease in the amount of horizontal shortening as expressed by these structures.

The Cranes Run fault forms the southern boundary of these structures; south of this fault, the rocks maintain a moderately steep dip. But the important contrast across this fault is the difference of trend: north of the fault the structures trend N70E; south of the fault, the beds trend N81E. This change is trend is locally significant, occurring in the same general area as the change in trend of the hinge of the Tuscarora anticlinorium. Although a relationship between these two trend changes is probable, it is unlikely that one was the cause of the other; rather, both of these trend changes probably reflect a fundamental change in the anticlinorium which was controlled by more regional processes operating at some depth below the present surface exposures. These trend changes constitute the surface expression of the curvature of the Valley and Ridge province in this area.

In the eastern part of the quadrangle, the same belt of Middle Devonian rocks exhibits a series of two anticlines and two synclines (the Barners Church folds) just north of the anticlinorium hinge. In contrast to the structures at Wardville, these folds are not associated with faulting, for no mappable faults were found in the vicinity. The significance of these folds is two-fold: the trend of their axial surfaces (N68E) differs from that of the anticlinorium hinge (N75E); and the folds originate as minor flexures in the limb of the anticlinorium, increasing in size and amplitude to the east (Figure 91). Because the bedding dips in the limbs of these folds are not significantly different from those across the anticlinorium limb to the west, the amount of shortening does not vary along this limb. The difference is that in the west the single large kink band comprises the anticlinorium limb, whereas to the east several smaller kink bands appear, giving rise to the Barners Church folds. The trend of these folds is similar to that of the Lock Ridge structures to the west, and thus represents a reappearance of this structural trend. This type of interfingering of trends represents another form of arcuation of the Valley and Ridge structures. The Oriental fault occurs north and northwest of the Barners Church folds, but does not appear to be part of these structures.

Quaker Valley Synclinorium

The Quaker Valley synclinorium lies north of the Tuscarora anticlinorium and has a similar change in trend across the quadrangle, bearing N67E in the western part and N73E in the eastern part. The 9 degree plunge of the syncline in the west decreases to subhorizontal in the east.

The hinge is a simple syncline in the west, but in the center of the quadrangle, it is replaced, en echelon, by another syncline. In the west, the syncline appears to be upright and symmetric, with moderately dipping beds in both limbs. In the east the hinge of the syncline is open, with variable but generally gentle dips in both limbs. The fold geometry here resembles that of the Trimmers Rock outcrop area to the south, where the folds are the eastward extensions of the Lock Ridge structures (see Tuscarora anticlinorium section above).

For 1 to 2 miles (1.6 to 3.2 km) north of the synclinorium hinge the bedding is generally moderately south dipping, with minor folds and kink bands scattered throughout. Two significant structures are present in the western and central parts of the quadrangle. An anticline-syncline fold pair, present in the area of Cocolamus, plunges and vanishes east-

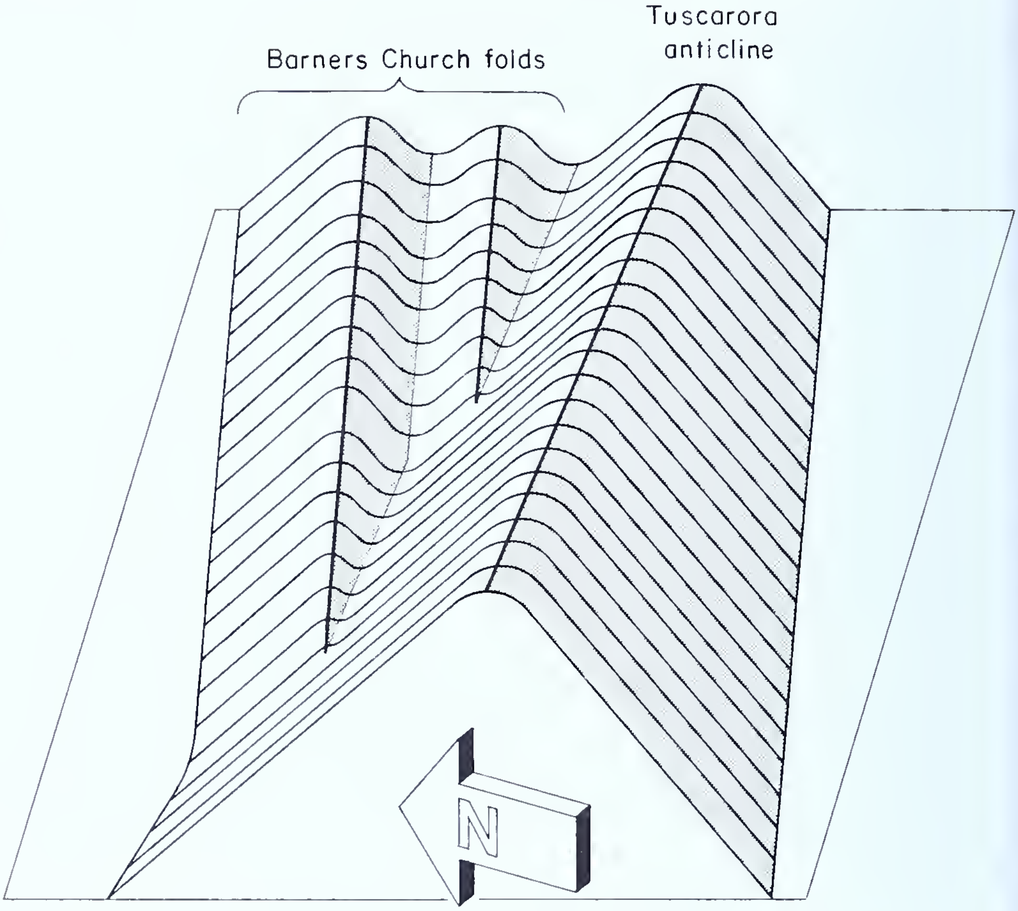


Figure 91. The Barners Church folds in the north limb of the Tuscarora anticlinorium, near the east boundary of the quadrangle. These folds, which trend more northeasterly than the main anticlinorium, increase in amplitude and size to the east.

ward near Kellerville. This structure has been previously discussed (p. 145, see also Faill, 1969) and is a multiple kink-band structure (Figures 65-67, p. 148-150). The other significant structure in the north limb of the Quaker Valley synclinorium is the Flint Ridge fault and associated folds. The Flint Ridge folds lie just north of the Cocolamus anticline-syncline fold pair and are terminated to the east by the Flint Ridge fault. As in the Cocolamus structures, the folds are fairly open in the west with moderate dips in the limbs (Figure 92). Eastward, the folds become smaller with a steeper dip in the south limb and a progressively gentler dip in the common limb. East and southeast of Evendale, along Flint Ridge, the fold pair terminates against a wedge fault in the Old Port Formation. The folds do not persist in the rocks above the fault;

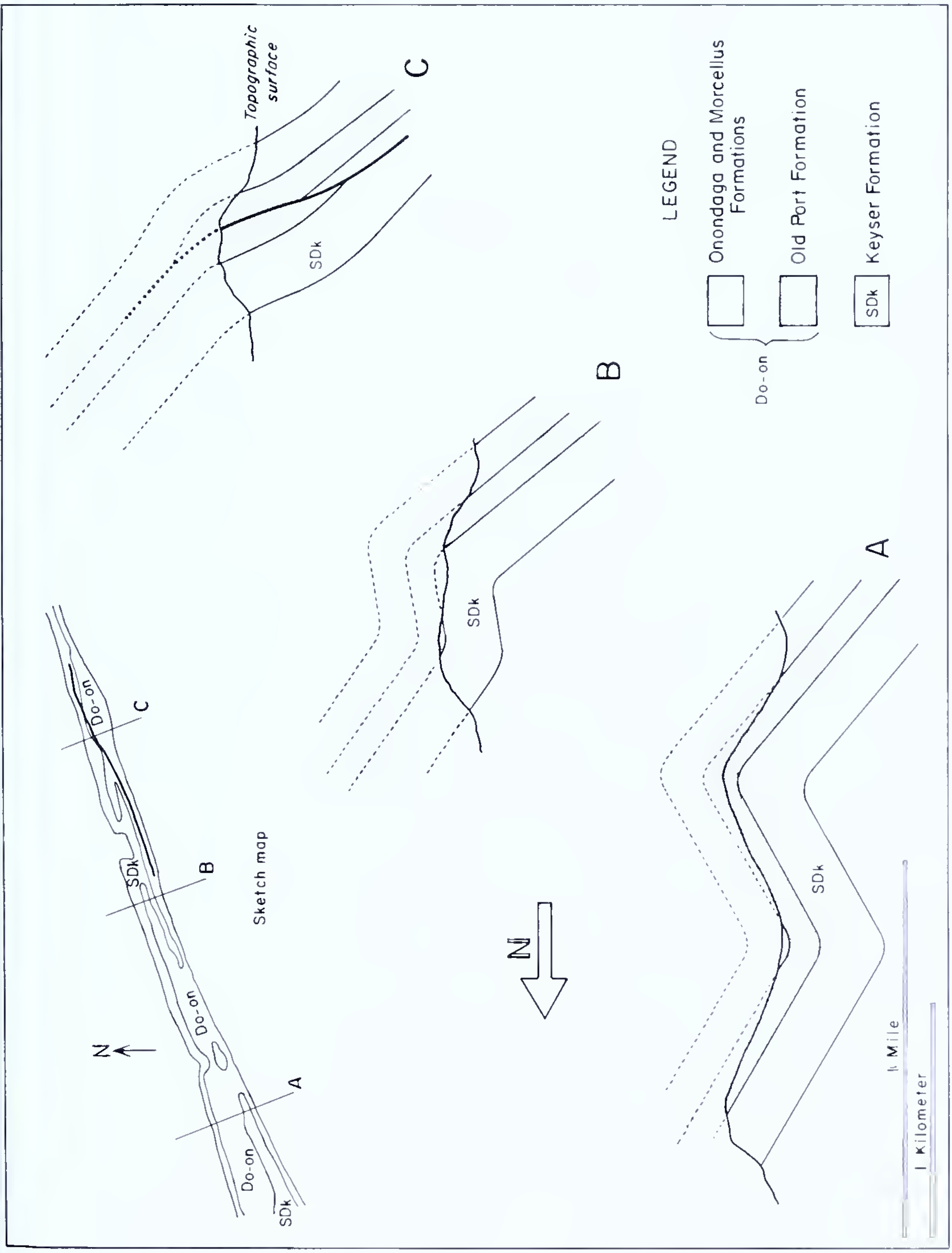


Figure 92. The Flint Ridge structure. The eastwardly diminishing folds are replaced by a fault.

the abnormally wide outcrop pattern in the Old Port Formation reflects a lessening of dip above the fault.

The Flint Ridge structures bear a great similarity to the Wildcat Ridge structures in the south limb of the Tuscarora anticlinorium. Except for the presence of a fault at the fold termination, the Flint Ridge structure is similar to the Cocolamus folds as well. In all three structures, there is a change of trend, and thus these structures appear to be a common form of arcuation in the province.

Shade Mountain Anticlinorium

The Shade Mountain anticlinorium, which occupies the northern third of the quadrangle, consists of a central anticline with major subsidiary folds on both limbs. Its hinge trends N75E in the western part and N65E in the eastern, a change in trend opposite to that which occurs in both the Tuscarora anticlinorium and the Quaker Valley synclinorium. The fold axis of the central anticline is nearly horizontal across the quadrangle, but just northeast of the quadrangle boundary, it plunges northeast at about 10 degrees.

The central anticline is relatively simple. To the west, in the Mifflintown quadrangle, the anticline appears to be upright and symmetrical, trending N65E and having a horizontal axis. At the western border of the Millerstown quadrangle, the fold becomes conjugate (Figure 93). It also becomes asymmetric with the appearance of small folds in the Tuscarora and Rose Hill rocks in the north limb and a shifting of the crest southward. These subsidiary folds trend N75E to N80E, and, in the east where the anticlinorium hinge trends N65E, they converge toward the hinge and die out.

In the south limb of the anticlinorium, the major subsidiary folds are Slim Valley Ridge anticline and Slim Valley syncline, which extend from the western border to the Mt. Pleasant Mills area in the northeast portion of the quadrangle. These folds are relatively simple in form except in the Mt. Pleasant Mills area where the Slim Valley syncline enlarges and develops into the Western Middle Anthracite syncline to the east (Wood and others, 1969). Near Mt. Pleasant Mills, numerous small folds are superimposed on the larger structures (Figure 94). Lime Ridge, occupying the hinge of Slim Valley syncline, consists of two to three small synclines and one to two intervening anticlines. On the south limb of Slim Valley Ridge anticline, there are several small periclinal folds of short length. At the eastern border, this anticline merges into the south limb of the Western Middle Anthracite syncline.

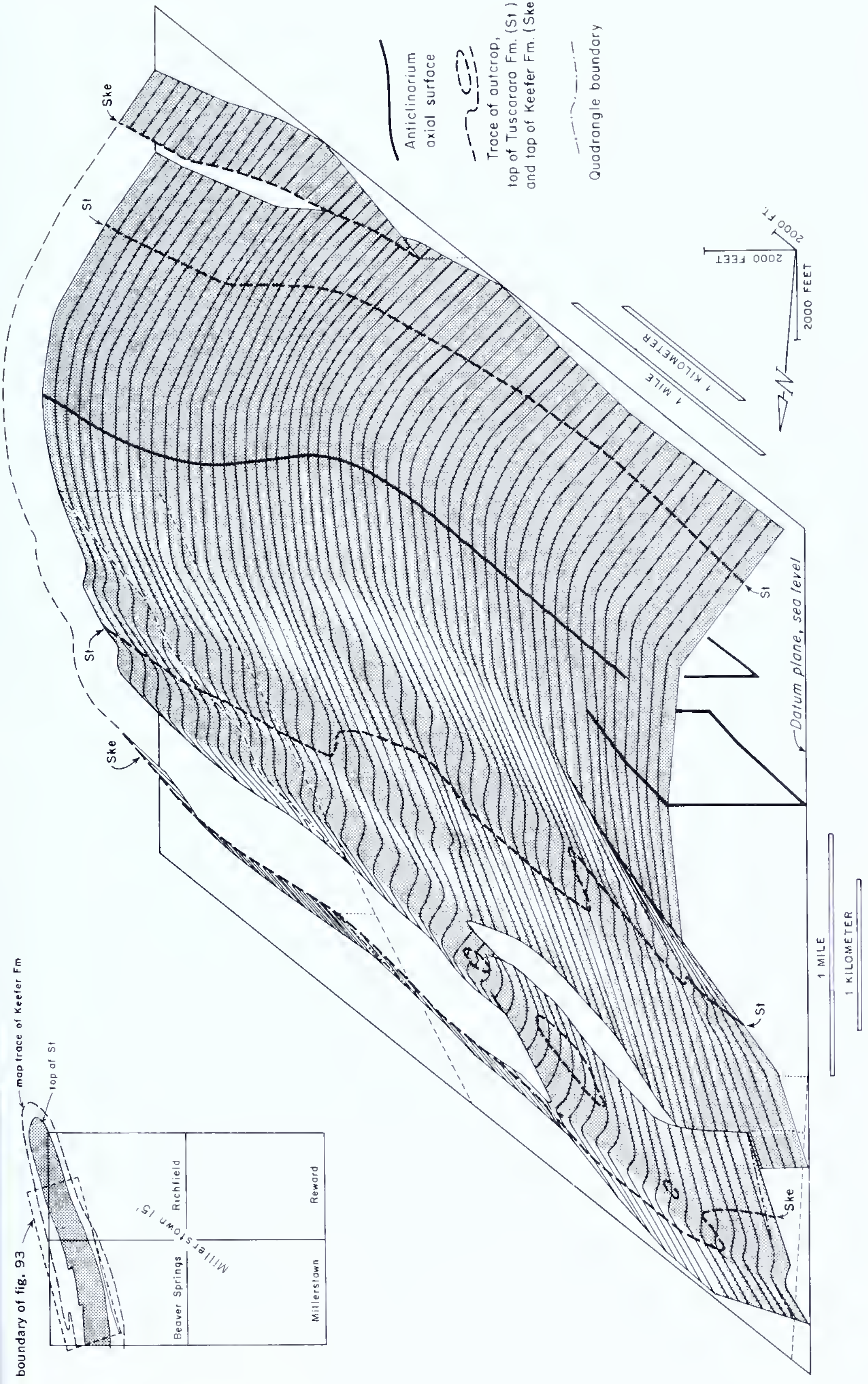


Figure 93. Change in geometry of the hinge and adjacent limbs of the Shade Mountain anticlinorium across the quadrangle.

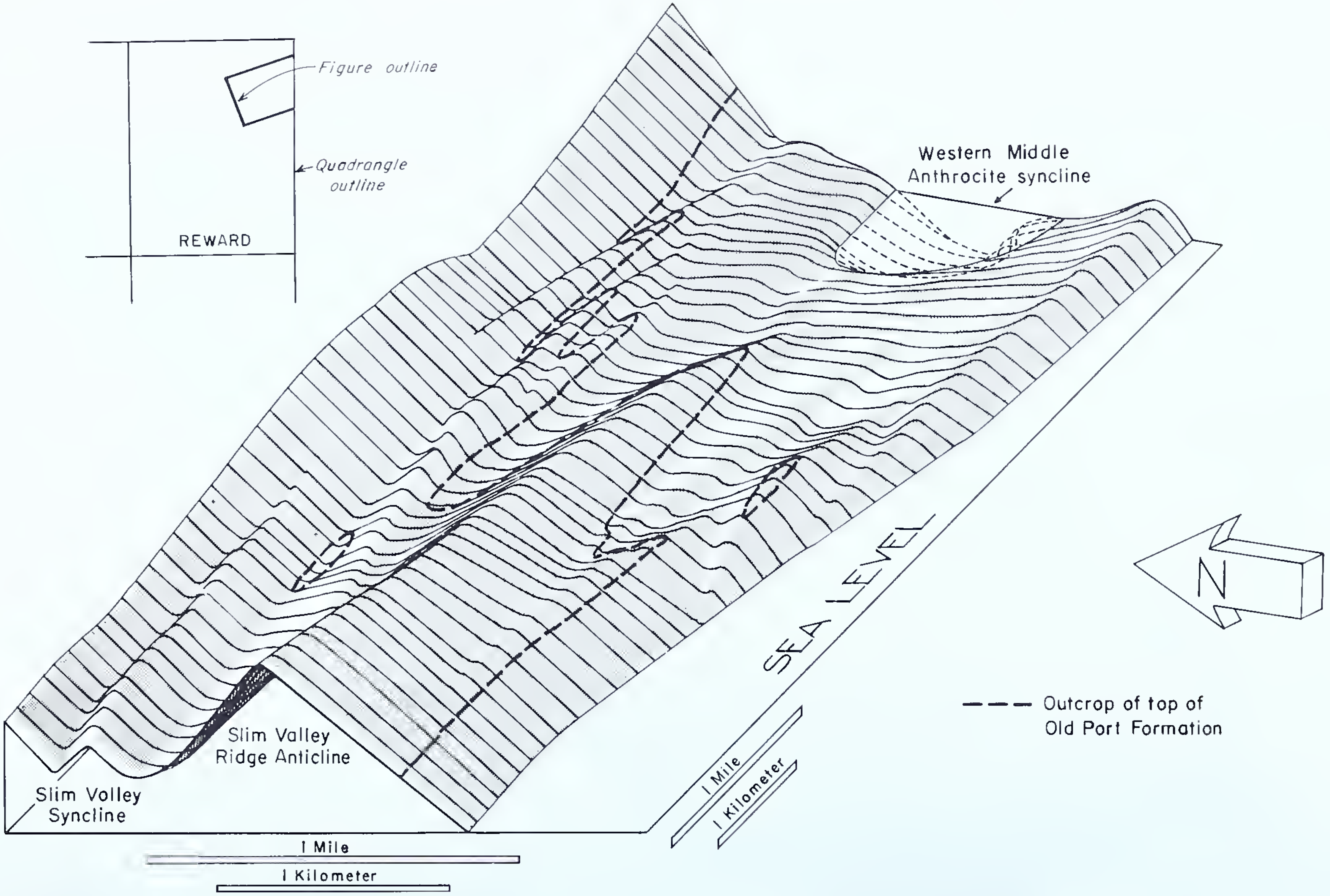


Figure 94. The eastwardly terminating Slim Valley anticline and the westwardly terminating Western Middle Anthracite syncline meet in a complex of small folds of short length in the Mt. Pleasant Mills area in the northeast portion of the quadrangle.

ENVIRONMENTAL GEOLOGY

Environmental geology concerns all of the aspects of the bedrock, soil, and water which have an effect on the human environment in a given area. This broad field includes aspects of hydrology, pedology, engineering geology, economic geology, and the analysis of geologic hazards. The mineral resources of the quadrangle are treated in the following section and studies of the origin, distribution, and utilization of soil types are being prepared on a county basis by the Soil Conservation Service of the U.S. Department of Agriculture.

The environmental geology discussion will emphasize hydrology and the engineering characteristics of the bedrock.

HYDROLOGY

Although detailed analysis of the water resources is beyond the scope of this report, some hydrologic data are presented and are related to the geology to provide basic information to water users. These data were collected from well drillers' reports, interim reports, and open-file reports of the Pennsylvania Geological Survey, and through personal communication with well drillers and well owners.

Surface Water

The major stream in the quadrangle is the Juniata River, which flows southeastward across the southwest corner of the quadrangle, as shown in the frontispiece. The Susquehanna River flows southward 1 to 5 miles (1.6 to 8 km) east of the quadrangle, and the confluence of these two rivers is 12 miles (19 km) south of the quadrangle. At that point the Susquehanna is about 85 miles (137 km) from the point where it enters Chesapeake Bay. The principal Susquehanna tributaries are Middle Creek, West Mahantango Creek, Bargers Run, Bucks Run, and Hunters Run. The streams which flow into the Juniata are Delaware Creek, Cocolamus Creek, Raccoon Creek, Wildcat Run, Howe Run, and Sugar Run. The areas of the drainage basins of these streams are listed in Table 22.

Annual precipitation is approximately 40 inches (Johnston, 1970), as measured at the stream gaging station at Newport. Records are also available from a gaging station which was maintained on Cocolamus Creek near Millerstown during the years 1930-1945. The average streamflow for the Juniata River from 1899 through 1967 was 4,195 cubic feet per second, which is the equivalent of 17.7 inches of precipitation per year for the basin drainage area above this point (Williams and George, 1968).

Table 22. *Basin Drainage Areas of Streams in the Millerstown Quadrangle*

Streams	Square miles	Square kilometers
Juniata River (above Newport)	3,354.0	8,686.9
Delaware Creek*	12.5	32.4
Cocolamus Creek*	57.2	148.1
Raccoon Creek*	21.5	56.7
Sugar Run*	2.8	7.3
Wildcat Run*	9.5	24.6
Howe Run*	3.7	9.6
Middle Creek	175.0	453.3
Mahantango Creek	86.2	223.3
Hunters Run	7.5	19.4
Bargers Run	13.0	33.7
Bucks Run	4.1	10.6

* Denotes streams draining into the Juniata River. Others drain into the Susquehanna River.

Williams and George conclude: "About half of the annual precipitation returns to the ocean by the river. The remaining water recharges the ground-water reservoir, provides moisture for vegetal growth, or is lost to the atmosphere by evaporation. Relatively little water is consumed by industrial processes in the basin." Johnston (1970) prepared a basin water budget for Cocolamus Creek (Table 23) which indicated that 45.6 percent of the precipitation falling on the basin flows out through Cocolamus Creek.

A considerable amount of sediment is transported by the tributary streams and by the two major rivers. Williams and Reed (1972) presented the following conclusions regarding sediment transport: (1) The amount of sediment transported down the Juniata River at Newport is equivalent to 79 tons per year per square mile of basin; (2) The sediment load for the Susquehanna River is equivalent to 110 tons per year per square mile of basin; (3) The average sediment size distribution of the stream-transported sediments in the Susquehanna basin is approximately 10 percent sand, 40 percent clay and 50 percent silt; and (4) Sediment load in the Susquehanna basin has been decreasing in recent years. For example, the sediment load in the Juniata River at Newport dropped by 25 percent between 1951 and 1967.

Subsurface Water

The water supply for most of the inhabitants in the quadrangle is derived from ground water by means of drilled wells. Pertinent data from

Table 23. *Water Budget for Cocolamus Creek Basin, Perry and Juniata Counties, Pennsylvania*

(Data from Johnston, 1970)

Gaging station:	Cocolamus Creek
Basin drainage area:	57.2 square miles
Precipitation station:	Newport, Perry County
Precipitation recorded:	1948–1957
Precipitation, inches/year	41.78
Average streamflow:	19.11 inches (45.7% of precipitation)
Average annual water loss (precipitation less runoff):	22.67 inches (54.3% of precipitation)

116 recent wells are presented in Appendix IV, A, and the wells are located on Plate 5. Average values of hydrologic data for each formation are presented in Appendix IV, B.

Most of the wells are less than 150 feet (46 m) deep and the water-bearing zones are generally encountered at less than 100 feet (30 m) (Figure 95). The yields of the water wells vary with their topographic locations; the lowest yields are from wells on hilltops and the highest yields from wells in the valleys (Table 24). The type of rock in which the well is drilled appears to have only a small influence on yield. Average yields from limestones in general are slightly higher than those from shales or sandstones (Table 25). On the other hand, much greater variation exists among the different rock formations (Figure 96). Wells in the Trimmers Rock and Tonoloway Formations possess the highest average yields, whereas those in the Mahantango, Onondaga, and Mifflintown Formations possess the lowest yields. This wide variation of yields among the limestones explains why the limestones, as a group, have average yields that are similar to the average yield of shales and sandstones.

These tables indicate that the optimum location for a water well in the Millerstown quadrangle is in a valley bottom which is underlain by limestone in the Tonoloway Formation, as in Pfoutz Valley and Raccoon Valley.

Water Quality

The quality of the ground water is of as much importance as the quantity. Seaber and Hollyday (1965) presented data on the Upper Silurian, Devonian, and Mississippian formations for the lower Susquehanna River basin (Table 26). Johnston (1970) compiled data on the Lower and Middle Silurian formations for two quadrangles adjacent to the Millerstown quadrangle (Table 26). Johnston concluded that "ground

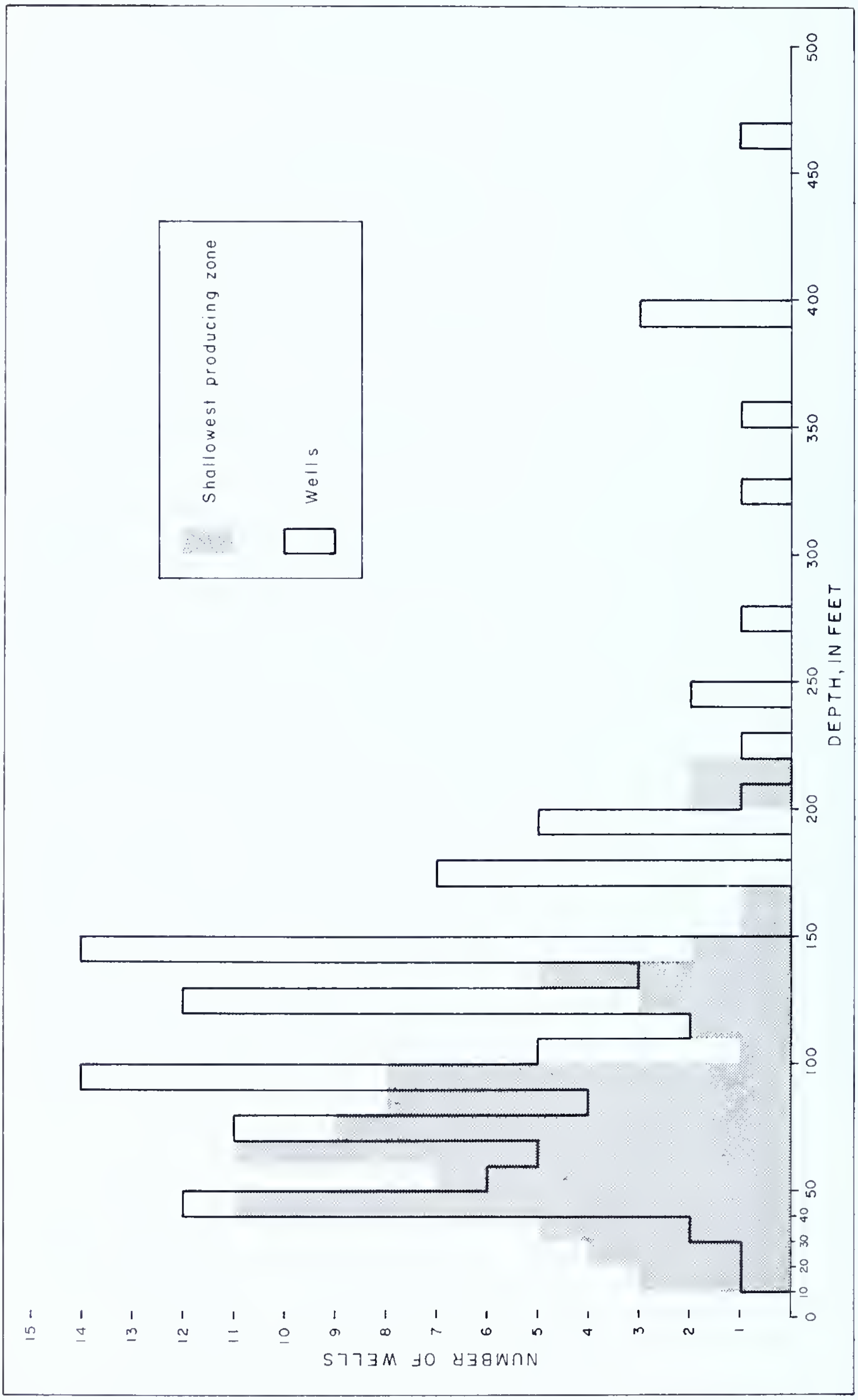


Figure 95. Histograms of well depth and reported depth to shallowest water producing zones. Data from 116 wells in the Millerstown 15-minute quadrangle.

Table 24. *Comparison of Average Yield with Topographic Location of Water Wells*

Well location	Average yield* (in gpm)	Number of wells
Hilltop	8	3 (4%)
Drainage divide	20**	4 (5%)
Slope	14	23 (30%)
Valley	28	47 (61%)

* Only those wells whose locations are known within 100 feet were used in computing these averages.

** This figure is questionable because of insufficient number of wells.

Table 25. *Comparison of Average Water Well Yield with the Reported Rock Type in the Producing Interval of the Well*

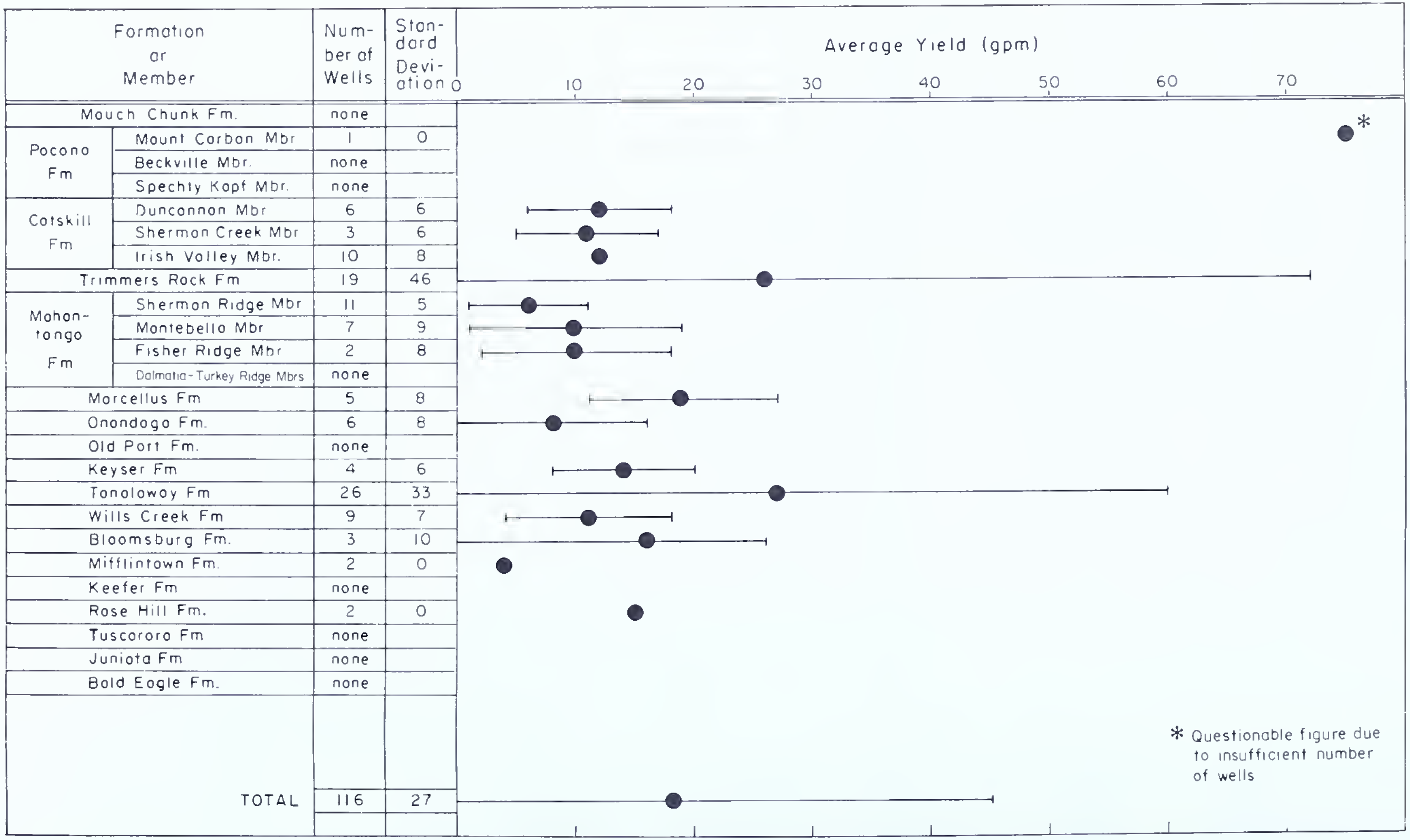
Rock type	Average yield (in gpm)	Number of wells
Limestone	16.6	26 (23%)
Shale	15.8	74 (65%)
Sandstone	15.2	13 (11%)

water from all rock units in this area is generally of good chemical quality. Water from calcareous shales and limestones generally has a dissolved solids content of 200 to 300 mg/l and is generally hard to very hard. Water from the non-calcareous shales and sandstones generally has a total dissolved solids content of 100 to 200 mg/l and is generally soft to moderately hard."

Water Use

Inasmuch as there is little industry and towns are relatively small and few, it is not surprising that the largest consumption of water is for domestic use. Industrial use amounts to less than 20 percent and the public water supplies account for the balance (Table 27).

The public water supplies are provided only for the larger communities: Millerstown, Thompsontown, Richfield, Beaver Springs, Beavertown, and Mt. Pleasant Mills. The water for these supplies is obtained from a combination of wells, springs, and mountain streams (Table 28).



Formation or Member		Number of Wells	Standard Deviation
Mauch Chunk Fm.		none	
Pocono Fm	Mount Carbon Mbr	1	0
	Beckville Mbr.	none	
	Spechty Kopf Mbr.	none	
Catskill Fm	Duncannon Mbr	6	6
	Sherman Creek Mbr	3	6
	Irish Valley Mbr.	10	8
Trimmers Rock Fm		19	46
Mahantongo Fm	Sherman Ridge Mbr	11	5
	Montebello Mbr	7	9
	Fisher Ridge Mbr	2	8
	Dalmatia-Turkey Ridge Mbrs	none	
Marcellus Fm		5	8
Onondaga Fm.		6	8
Old Port Fm.		none	
Keyser Fm		4	6
Tonoloway Fm		26	33
Wills Creek Fm		9	7
Bloomsburg Fm.		3	10
Mifflintown Fm.		2	0
Keefer Fm		none	
Rose Hill Fm.		2	0
Tuscarora Fm		none	
Juniata Fm		none	
Bald Eagle Fm.		none	
TOTAL		116	27

* Questionable figure due to insufficient number of wells

Figure 96. Average yield and range of yield (in gpm) of water wells located in each geologic unit, Millerstown quadrangle. Based on data listed in Appendix IV.

Table 26. *Quality of Ground Water in Geologic Units in the Millerstown Quadrangle*

(Data for Keyser, Wills Creek, Tonoloway, and all younger units are taken from Seaber and Hollyday (1965) and are valid for the entire lower Susquehanna basin. Data for Bloomsburg, Mifflintown, and Rose Hill Formations are from Johnston (1970) and apply to the lower Juniata River valley only.)

Geologic unit (formation or group)	Chemical characteristic category	Temperature (°F)	Silica (SiO_2)	Total iron (Fe)	Total manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids (residue at 180°C)	Calcium magnesium hardness as $CaCO_3$	Alkalinity	pH	Remarks
Mauch Chunk	Good	—	—	0.0	—	—	—	—	—	—	20	1.5	—	—	130	90	60	7.1	
	Medium	55	17	0.1	—	50	5.7	12	2.4	120	40	2.5	0.1	2.1	160	110	80	7.4	
	Poor	—	—	0.8*	—	—	—	—	—	—	60	3.5	—	—	190	130	100	7.7	
Pocono	Good	—	—	2.0*	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
	Medium	57	—	2.7*	—	10	—	2.4		40	3	1.0	—	—	39	32	—	—	
	Poor	—	—	3.4*	—	—	—	—	—	—	—	—	—	—	—	—	—	—	
Catskill	Good	—	—	0.0	—	—	—	—	—	—	—	0.4	—	—	90	50	45	7.0	
	Medium	54	12	0.2	—	17	13	15	3.2	53	15	7	—	16	130	80	65	7.2	
	Poor	—	—	0.4*	—	—	—	—	—	—	—	10	—	—	170	110	85	7.4	
Trimmers Rock-Harrell	Good	53	—	0.2	—	30	13	8		70	5	0	—	—	100	100	—	—	Occasional reports of hydrogen sulfide.
	Medium	54	—	0.5*	—	40	18	10		100	45	20	—	1.0	200	150	—	—	
	Poor	55	—	0.8*	—	50	23	12		130	85	40	—	—	300	200	—	—	
Onondaga, Marcellus, and Mahantango	Good	52	—	0.0	—	28	3.2	4		90	0	0		0.0	100	80	70	6.9	Several reports of hydrogen sulfide odor.
	Medium	54	15	1.4*	—	42	4.5	10		130	20	20	—	0.2	170	130	95	7.2	
	Poor	56	—	2.8*	—	56	5.8	16		170	40	40	—	0.4	240	180	120	7.5	
Old Port	Good	52	—	0.2	—	30	6	3		110	10	0	—	—	100	90	80	—	A few samples indicate a high hardness and dissolved-solids content.
	Medium	53	—	0.4*	—	50	10	4		150	30	2	—	—	160	170	160	7.3	
	Poor	54	—	0.6*	—	70	14	5		190	50	4	—	—	320	250	240	—	

Table 26. *(Continued)*

Geologic unit (formation or group)	Chemical characteristic category	Temperature (°F)	Silica (SiO_2)	Total iron (Fe)	Total manganese (Mn)	Calcium (Ca)	Magnesium (Mg)	Sodium (Na)	Potassium (K)	Bicarbonate (HCO_3)	Sulfate (SO_4)	Chloride (Cl)	Fluoride (F)	Nitrate (NO_3)	Dissolved solids (residue at 180°C)	Calcium magnesium hardness as $CaCO_3$	Alkalinity	pH	Remarks
Keyser, Tonoloway, and Wills Creek	Good Medium Poor	52 53 54	9 11 13	0.0 0.1 0.2	— — —	60 90 120	15 30 45	0.0 10 20		140 200 260	20 70 120	0 4 8	— — —	0 6 12	200 280 360	130 200 270	130 150 170	7.4 7.6 7.8	A few samples indicate exceedingly high calcium sulfate and iron concentrations.
Bloomsburg		52	10	0.4	0.01	40	11	4.3	0.6	153	11	7	0	15	178	138	—	6.8	
Mifflintown		52	7.4	0.5	0.00	55	4.6	1.0	0.5	154	10	5	0.1	15	192	156	—	7.4	
Rose Hill		—	9.3	0.8	0.31	10	5.7	2.6	0.5	64	3	1.5	0.0	0.6	74	47	—	6.9	

Values in parts per million except as indicated.

Chemical characteristic category: Values tabulated are taken from a normal frequency distribution of reported chemical analyses of well water. Good, medium, and poor refer to values equaled or exceeded for 75, 50, and 25 percent of available analyses, respectively.

* Exceeds limits listed in *Drinking Water Standards*, 1962, U.S. Public Health Service.

Table 27. *Ground-Water Use, in Gallons per Day, in Juniata, Perry, and Snyder Counties*

(Data from Pennsylvania Geological Survey, 1956)

County	Public supply	Industrial use	Rural use
Juniata	300,000	less than 100,000	500,000
Perry	300,000	200,000	800,000
Snyder	500,000	less than 100,000	700,000

Table 28. *Public Water Supplies Serving Areas of the Millerstown Quadrangle*

(Data from Pennsylvania Department of Commerce, Division of Statistics, Pennsylvania Department of Forests and Waters, and U.S. Geological Survey, Water Resources Division. Population data and consumption figures are for 1967.)

Facility	Area served	Estimated population served	Yearly supply (millions of gallons)	Sources of water and capacity	Number of subscribers	Average daily consumption (gallons) Total	Per capita
Beavertown	Beavertown and part of Beaver Twp.	800	49	Luphers Run surface supply 100,000 gpd; 2 wells for emergency use, combined cap. 37,000 gpd	294	112,602	140
Beaver Springs Municipal Authority	Beaver Springs	—	—	—	—	—	—
Richfield Area Joint Authority	Richfield and Mount Pleasant Mills	805	28.3	2 wells; 2 springs; 74,000 gpd	234	70,731	87
Thompsontown Municipal Authority	Thompsontown and part of Delaware Twp.	750	23.4	2 wells, 1 spring, Platte Hollow surface supply; storage capacity 188,000 gal.	263	41,096	54
Millerstown Borough Water Works	Millerstown and part of Delaware Twp.	880	65.8	1 well, 6 springs; 57,000 gpd	222	62,350	70

Flood Hazard

As with all areas of sizable annual rainfall and a well-developed drainage system, some danger of flooding exists. However, in that the floodplains of all the streams and rivers are relatively narrow, only the areas immediately adjacent to the streams are usually subject to flooding. Floods occur on the lesser streams as well as on the major rivers, and the data from Cocolamus Creek (Table 29) suggest that flooding on the tributaries is more frequent than on the major rivers (Table 30).

Frequency of flooding varies throughout the year, being greatest during the early spring months (Figure 97) when the combination of higher rainfall and melting snow increases the discharges in the streams. Winter thaws also contribute to flooding during the winter months, especially on

Table 29. *Frequency and Magnitude of Flooding on Cocolamus Creek in Pfoutz Valley, Perry County, Pennsylvania*

(Data from Busch and Shaw, 1960)

Location: Lat. 40°33′55″, long. 77°07′05″, on right bank 10 ft. upstream from bridge on Pa. Route 17, 2.3 miles northeast of Millerstown, Perry County, and 3 miles upstream from mouth.
Drainage area: 57.2 sq. mi.
Gage: Recording gage. Datum of gage is 425.50 ft. above mean sea level (Pennsylvania State Highway benchmark).
Stage-discharge relation: Defined by current-meter measurements.
Bankfull stage: 5 ft.
Remarks: Base for partial-duration series, 1,000 cfs (U.S. Geological Survey Gaging Station 5665).
Date of records: 1930 through 1945.

Gage height (feet)	Discharge (cfs)	Number of floods which equalled or exceeded this level during this 16-year period	Average frequency of flooding
8.5	5,000	none	
8.0	4,500	3	5 years, 3 months
7.7	4,000	5	3 years, 2 months
7.3	3,500	10	1 year, 7 months
7.0	3,000	15	1 year, 1 month
6.4	2,500	21	9 months
6.0	2,000	29	7 months
5.4	1,500	45	4 months
(bankfull stage, 5.0 feet)			
4.5	1,000	95	2 months
3.0	500	97	2 months

the tributaries. Cocolamus Creek and Mahantango Creek appear to be more susceptible to flooding than the other streams, which have little or no floodplains. Flood hazard along the Juniata River is quite restricted because of its relatively narrow valley.

Table 30. *Frequency and Magnitude of Flooding on the Juniata River at Newport, Pennsylvania*

(Data from Busch and Shaw, 1960)

Location: Lat. 40°28′45″, long. 77°07′45″, on right bank at downstream side of highway bridge at Newport, Perry County, 1,000 feet upstream from Little Buffalo Creek.

Drainage area: 3,354 sq. mi.

Gage: Nonrecording gage prior to July 16, 1929; recording gage thereafter. Datum of gage is 363.93 ft. above mean sea level, datum of 1929.

Stage-discharge relation: Defined by current-meter measurements below 100,000 cfs and extended above.

Bankfull stage: 22 ft.

Remarks: Base for partial-duration series, 29,000 cfs. Only annual peaks are shown prior to Oct. 1, 1913 (U.S. Geological Survey Gaging Station 5670).

Date of records: 1899 through 1958.

Gage height (feet)	Discharge (cfs)	Number of floods which equalled or exceeded this level during this 60-year period	Average frequency of flooding
36.0	210,000	none	
35.1	200,000	1	60 years
34.2	190,000	2	30 years
33.0	180,000	2	30 years
31.9	170,000	2	30 years
30.8	160,000	2	30 years
29.7	150,000	2	30 years
28.6	140,000	2	30 years
27.5	130,000	2	30 years
26.4	120,000	2	30 years
25.3	110,000	3	20 years
24.2	100,000	5	12 years
22.0	90,000	6 (bankfull stage)	10 years
20.6	80,000	7	8 years, 7 months
20.0	70,000	11	5 years, 5 months
16.9	60,000	15	4 years
15.9	50,000	33	1 year, 10 months
13.9	40,000	56	1 year, 1 month
12.5	30,000	94	8 months
9.7	20,000	104	7 months
6.9	10,000	105	7 months

ENGINEERING GEOLOGY

Engineering geology is the application of geological science to engineering practice so that geological factors affecting the location, design, construction, operation, and maintenance of engineering works are recognized and adequately provided for. In the Millerstown quadrangle, the different rock types exhibit contrasting properties with respect to ground-water potential, foundation stability, slope stability, and ease of excavation. In Table 31, each of the rock units (formations) is evaluated in terms of these and other categories. An explanation of each category and the ratings is given at the end of this section.

In general, rocks of similar lithology will exhibit similar properties. Sandstones tend to resist weathering and erosion in the humid, temperate climate of Pennsylvania and thus disintegrate only gradually. Because of this, they are difficult to excavate, make good foundation support, and possess high slope stability. On the other hand, shales (particularly the calcareous shales) disintegrate readily and thus tend to be easily excavated, possess low slope stability, and make poorer foundation support. All of the formations have been categorized into five groups

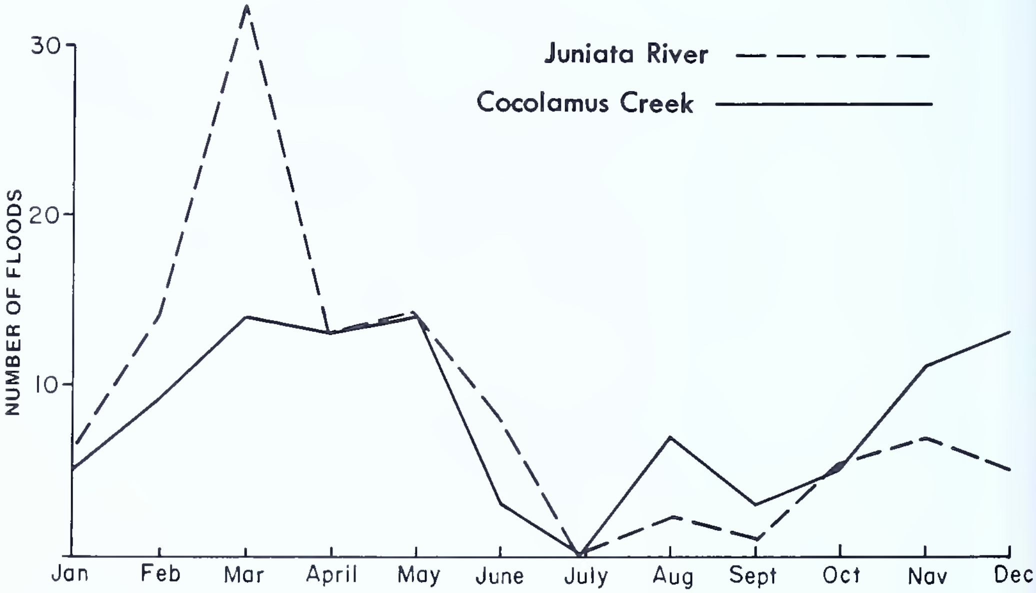


Figure 97. Monthly distribution of flooding on Cocolamus Creek and the Juniata River. Records from Cocolamus Creek cover the years 1930 through 1945, obtained at the gaging station east of Millerstown; records from the Juniata River cover the years 1899 through 1958 and were obtained at Newport. Data from Busch and Shaw, 1960.

depending upon these engineering properties, and the distribution of the groups is illustrated in Plate 5.

It is important to recognize that the properties of a given rock can vary greatly with depth and degree of weathering. Therefore, the geologic criteria for judging the rock units vary for each category. For aquifer potential, the criteria refer to unweathered rock because virtually all water wells penetrate bedrock.

Few of the rock formations possess the same lithology throughout. Many consist of interbedded sequences of two different lithologies (e.g., interbedded siltstone and shale of the Trimmers Rock Formation, seen in Figure 38). The larger, more prominent changes of lithology within a formation have been mapped as members or submembers (e.g., the "iron sandstones" of the Rose Hill Formation, the Center and Cabin Hill Members), but smaller interbedded units occur throughout the stratigraphic section (e.g., in the Irish Valley Member of the Catskill Formation). Systematic changes in lithology also occur within single units, such as the upward-coarsening cycles of the Mahantango and the upward-fining cycles in the Catskill Formation. In addition, the lithology of a unit can change from one part of the map area to another (e.g., the northward fining of the Mahantango).

The Categories of Rock Characteristics

Map Symbol and Formation (or Member) Name

The map symbols and formation and member names are the same as used on the geologic map (Plate 1) and the tectonic-environmental map (Plate 5). These symbols relate specific localities or patterns on the maps to the appropriate rock unit in Table 31.

Thickness

Values given are the average thickness of each unit. If there is a considerable variation in thickness across the map, the range of thicknesses is also given.

Lithology

The predominant lithic type or types are listed, with the understanding that other rock types may be present in subordinate amounts. For a detailed description of a unit, refer to Table 2 or to the chapter on stratigraphy.

Weathering

Weathering is the chemical and mechanical disintegration of rock constituents into small grains or fragments. Under the humid, temperate

Table 31. *Engineering Characteristics of the Lithologic Units in the Millerstown Quadrangle*

Map symbol	Formation or member	Thickness	Lithology	Aquifer potential	Weathering character	Slope stability	Fractures	Excavation difficulty	Foundation strength
Mmc	Mauch Chunk	2,000+ ft. (610) m)	Red shales and siltstones, minor sandstones and conglomerate	No data available	Moderate to high disintegration, moderate to deep depth	Moderate to low	Low density, poorly developed	Easy to moderate	Moderate
DMp	Pocono	1,500 ft. (457 m)	Sandstones, conglomerates	No data available	Low disintegration, bouldery and cobbly soil	High	Low density, well developed	Requires blasting and heavy equipment	High
Dcd	Catskill, Duncannon Member	1,900–3,000 ft. (579–914 m)	Sandstone, red siltstone and shale	Moderate	Moderate disintegration, moderate depth	Moderate to high	Moderate to low density, well developed	Requires blasting and heavy equipment	High
Dcs	Catskill, Sherman Creek Member	1,500–2,700 ft. (457–821 m)	Red shale and siltstone	Moderate	Moderate to low disintegration, moderate depth	Moderate	Moderate density, moderately well developed	Moderate, may require blasting	Moderate
Dci	Catskill, Irish Valley Member	2,500–3,150 ft. (762–960 m)	Sandstone, siltstone, and shale	Moderate	Moderate to low disintegration, moderate depth	Moderate	Moderate density, well developed	Requires blasting and heavy equipment	Moderate to high
Dth	Trimmers Rock-Harrell	2,200–2,700 ft. (670–823 m)	Siltstone and shale	High	Moderate to rapid disintegration, moderate to low depth	Moderate to low	High density, very regular, very well developed	Moderate	Moderate to low
Dms	Mahantango, Sherman Ridge Member	500–700 ft. (152–213 m)	Siltstone, shale	Low	Rapid to moderate disintegration, low to moderate depth	Low	Low to moderate density, poorly to moderately well developed	Easy to moderate	Moderate

Dmm	Mahantango, Montebello Member	200–900 ft. (61–274 m)	Sandstone, siltstone, minor conglomerate	Moderate	Low to moderate, cobbly to bouldery soil, low depth	High to moderate	Low to moderate density, well developed	Difficult to moderate, requires blasting and heavy equipment	High to moderate
Dmf	Mahantango, Fisher Ridge Member	100–700 ft. (30–213 m)	Siltstone and shale, some sandstone	Moderate	Rapid to moderate disintegration, low to moderate depth	Moderate to low	Low density, splintery, moderately well developed	Easy to moderate	Moderate to low
Dmd	Mahantango, Dalmatia Member	0–200 ft. (60 m)	Sandstone	No data available	Low disintegration, low to moderate depth	High	Low to moderate density, well developed	Difficult, requires blasting and heavy equipment	High
Dmt	Mahantango, Turkey Ridge Member	100 ft. (30 m)	Sandstone	No data available	Low disintegration, low to moderate depth	High	Low to moderate density, well developed	Difficult, requires blasting and heavy equipment	High
Dmr	Marcellus	106 ft. (32 m)	Black shale	Moderate	Rapid disintegration, splintery, moderate to deep depth	Low	Low to moderate density, splintery, moderately well developed	Easy	Moderate to low
Don	Onondaga	165 ft. (50 m)	Limestone and calcareous shale	Low	Deep leaching, deep depth	Low	Moderate density, well developed	Easy to moderate	Low
Do	Old Port	50–100 ft. (15–30 m)	Chert and shale, some sandstone	No data available	Low disintegration, cobbly soil, low depth	Moderate to high	High density, well developed, irregular	Easy to moderate	Low to moderate

Table 31. *(Continued)*

Map symbol	Formation or member	Thickness	Lithology	Aquifer potential	Weathering character	Slope stability	Fractures	Excavation difficulty	Foundation strength
SDk	Keyser	150–200 ft. (46–61 m)	Nodular limestone	Moderate	Moderate leaching and disintegration, moderate depth	Low to moderate	High density, well developed	Moderate	Moderate
Sto	Tonoloway	500–600 ft. (152–183 m)	Laminated limestone	High	Deep leaching, deep depth	Low	Moderate density, moderately well developed	Easy to moderate	Low to moderate
Sw	Wills Creek	600–800 ft. (183–244 m)	Calcareous shale and silty shale	Moderate	Rapid disintegration, moderate to deep depth	Low	Low density, tendency to splinter	Easy	Low
Sb	Bloomsburg	450–480 ft. (137–146 m)	Red shale and siltstone	Moderate	Rapid to moderate disintegration, moderate to deep depth	Low	Low density, splintery	Easy	Low
Sm	Mifflintown	159 ft. (48 m)	Limestone and calcareous shale	Low	Moderate to deep leaching, moderate to deep depth	Low	Moderate density, moderately well developed	Easy to moderate	Low to moderate
Ske	Keefer	38 ft. (12 m)	Sandstone	No data available	Low disintegration, bouldery soil, low depth	High	Low to moderate density, well developed	Difficult, requires blasting and heavy equipment	High
Sru, Srm, Srl	Rose Hill, Upper, middle, and lower shaly members	855 ft. (261 m)	Shale, calcareous in upper member	Moderate	Moderate to rapid disintegration, moderate to deep depth	Low to moderate	Low density, splintery	Moderate	Moderate

Src, Srch	Rose Hill, Center and Cabin Hill Members	79 and 12½ ft. (24 and 4 m)	Iron sandstone	No data available	Low to moderate disintegration, low to moderate depth	High	Moderate to high density, well developed	Moderate to difficult, may require blasting and heavy equipment	Moderate to high
St	Tuscarora	600 ft. (183 m)	Quartzite	No data available	Low disintegration, bouldery soil, low to moderate depth	High	Low density, well developed	Difficult, requires blasting and heavy equipment	High
Oju, Ojl	Juniata	750 ft. (229 m)	Red sandstone, siltstone, and shale	No data available	Low to moderate disintegration, low to moderate depth	High to moderate	Low to moderate density, well developed	Difficult, requires blasting and heavy equipment	High
Obe	Bald Eagle	730 ft. (223 m)	Sandstone and conglomeratic sandstone	No data available	Low disintegration, bouldery soil, low depth	High	Low density, well developed	Difficult, requires blasting and heavy equipment	High

climate of Pennsylvania, chemical weathering (dissolving or leaching) is restricted chiefly to limestones and to certain calcite-cemented detrital rocks. These rocks tend to be rapidly leached, develop a deep soil, and occur in the valley bottoms. All of the other rocks undergo physical disintegration (the breaking up of the rocks into smaller fragments and individual mineral grains). The silica-cemented sandstones undergo the slowest weathering, develop a thin, bouldery soil, and underlie the higher ridges. Shales disintegrate fairly rapidly, develop a moderate amount of soil, and underlie hill slopes and valleys.

The depth of soil is related both to rapidity of weathering and to topographic location. Low soil depths (0 to 10 feet, 0 to 3 m) tend to occur on the ridge crests and adjacent slopes. Moderate soil depths (10 to 20 feet, 3 to 6 m) tend to occur at the base of the ridges and in the valley floors. Depths greater than 20 feet (6 m) are restricted to the limestones.

Fracturing

Although fractures are ubiquitous in the rocks, the nature of the fractures varies with lithology. Fractures can be planar or irregular, but of greater importance to weathering, slope stability, and excavation is the fracture density, or number of fractures per foot. A low fracture density indicates a spacing between fractures of more than 2 feet (.7 m). A moderate density ranges from 6 inches to 2 feet (.15 to .7 m), whereas a high density refers to a spacing of less than 6 inches (.15 m).

The disintegration of the coarser detrital rocks (siltstones and sandstones) depends largely on the fracture density, but the shales tend to break up regardless of the observable fracture spacing. In some shales, as the Bloomsburg, an incipient closely spaced fracture cleavage aids in the disintegration.

Aquifer Potential

This category refers to the average ground-water-producing capability of each unit. These data are based predominantly on domestic well information. Low potential means the average well yield is less than 10 gallons per minute (gpm), moderate potential is 10 to 20 gpm average yield, and high potential refers to average yields in excess of 20 gpm. The average yield of wells in the quadrangle for each formation, and the range of yields, are presented in Figure 96. The units with the highest yields are the Trimmers Rock and Tonoloway Formations.

Aquifer potential for a given stratigraphic unit will vary depending on the topographic and structural location of the well and internal variations in porosity and permeability. Aquifer potentials tend to be most favorable in topographically low areas (e.g., in valley bottoms) and least favorable in topographically high positions (e.g., ridge tops), as indicated in Table 24. Aquifer yields are generally greater near the center of synclines, and least favorable near the centers of anticlines. Yields also tend to be greater in the immediate vicinity of faults (Plate 5).

Slope Stability

The stability of natural and artificial slopes depends on a number of factors, such as weathering, fracture density, and the fracture or bedding orientation. Natural slopes are for the most part fairly stable, moving only by slow creep. The steepness of a natural slope is a fair indicator of the stability of the underlying rock; the rocks underlying the steeper slopes tend to have higher slope stabilities. However, natural slopes can become unstable if they are undercut at their base, or if they are excessively loaded by man-made structures. Of particular importance to slope stability is the orientation of bedding or prominent fractures. If either is parallel to the slope, the likelihood of slope failure (landslide, accelerated creep) is enhanced if the slope is undercut or loaded.

Slope stability also varies with the degree of weathering, an important consideration in creating artificial slopes. The less weathered rock will maintain a steeper slope than the weathered rock. Rate of weathering is also significant. Steep artificial slopes will persist for long periods of time in rocks that disintegrate slowly, whereas slope stability will be much less in rocks that disintegrate rapidly.

The criteria in Table 31 used for evaluating slope stability are only relative. A low slope stability rating indicates that the slope would be unstable with minor undercutting or loading. A moderate rating refers to slopes that can sustain some undercutting and loading with little likelihood of movement. High stability is applied to those rocks which can maintain a steep slope indefinitely.

Foundation Stability

Inasmuch as many light structures are built on soil or partially weathered rock, the primary concern for foundations is slope stability. Heavier structures should be founded on bedrock. The bedrock for all units has high foundation stability with two exceptions: areas of moderate to steep slope on units which weather moderately or rapidly; and limestone areas, which may contain caves, solution cavities, and sinkholes (particularly the Tonoloway limestone).

The ratings of the units (see Table 31) are based primarily on slope stability and depth to bedrock. Areas of low foundation stability would require floating foundations or foundations on bedrock for heavy loads. Areas of moderate foundation stability might require piers or piles for heavy structures. In a high foundation stability area, conventional footings would be adequate.

Ease of Excavation

Ease of excavation is dependent on the nature of the rock, depth of weathering, and the depth to which excavation is carried. Excavation of most units, except the siliceous sandstones and quartzites, would be easy for depths to 5 or 10 feet (1.5 to 3 m). Difficulty increases with increasing depth.

Sandstone and limestone bedrock is the most difficult to excavate, requiring blasting and heavy equipment. However, bedrock would not be encountered in most excavations over limestone because of its deep soil. Shale and siltstone bedrock with a high fracture density would be easier to excavate, by ripping and with a power shovel. Only the partially and completely weathered rocks would be easily removed with light equipment.

MINERAL RESOURCES

At the present time, the mineral extraction industry (quarrying and mining) in the Millerstown quadrangle is restricted to the production of crushed stone for local use. Mineral commodities which have been produced in the past include sedimentary iron ore, clay shale for brick manufacture, agricultural lime, and building stone. Other potentially useful minerals which occur in the quadrangle include fluorite and wad (manganese oxide), but these have not been found in commercial amounts. Anthracite coal occurrences are restricted to a few thin, discontinuous, noncommercial beds (less than one inch thick) in the Catskill and Pocono Formations. There is a possibility of future petroleum production in the area.

The principal quarries and mines are listed in Table 32, and are located on the tectonic and environmental geology map (Plate 5).

LIMESTONE

Limestone from the basal part of the Keyser Formation has been extensively quarried in this region to provide agricultural lime. This part of the Keyser is particularly suitable because of its high purity (more than 85 percent calcium carbonate, less than 10 percent acid insoluble residue), which the other limestones do not possess. Miller (1934) lists about 18 limestone quarries in the quadrangle, some of them dating from colonial times. However, with the recent availability of commer-

Table 32. *Quarries and Mines in the Millerstown Quadrangle*

(Locations are plotted on Plate 5)

Map no.	Formation or member	Location	Status	Product
1	Keefer Fm. (sandstone)	Tuscarora Mtn.	abandoned	iron ore
2	Keefer Fm. (sandstone)	Slaughterback Hill	abandoned	iron ore
3	Bloomsburg Fm. (claystone)	Beavertown	inactive	clay
4	Bloomsburg Fm. (claystone)	Beavertown	inactive	clay
5	Tonoloway Fm.	Kurtz Valley	abandoned	limestone
6	Keyser and Tonoloway	Lost Creek Ridge	active	limestone
7	Keyser Fm.	Pfoutz Valley	abandoned	limestone
8	Keyser Fm.	Pfoutz Valley	abandoned	limestone
9	Keyser Fm.	Pfoutz Valley	inactive	limestone
10	Keyser Fm.	Little Pfoutz Valley	abandoned	limestone
11	Keyser Fm.	Raccoon Creek Valley	inactive	limestone
12	Keyser Fm.	Delaware Ck. Valley	abandoned	limestone
13	Keyser Fm.	Delaware Ck. Valley	abandoned	limestone
14	Keyser Fm.	Potato Valley	inactive	limestone
15	Keyser Fm.	Lime Ridge	inactive	limestone
16	Keyser Fm.	Lime Ridge	inactive	limestone
17	Keyser Fm.	Lime Ridge	inactive	limestone
18	Keyser Fm.	Firestone Ridge	abandoned	limestone
19	Old Port Fm. (chert)	Lock Ridge	inactive	crushed stone
20	Old Port Fm. (chert)	White Oak Hollow	inactive	crushed stone
21	Old Port Fm. (chert)	Delaware Creek Valley	inactive	crushed stone
22	Old Port Fm. (chert)	Kurtz Valley	inactive	crushed stone
23	Old Port Fm. (chert)	Firestone Ridge	active	crushed stone
24	Old Port Fm. (chert)	Firestone Ridge	inactive	crushed stone
25	Marcellus Fm. (shale)	Wardville	abandoned	crushed stone
26	Marcellus Fm. (shale)	Thompsontown	active	crushed stone
27	Fisher Ridge Mbr., Mahantango Fm.	Donnally Mills	abandoned	crushed stone
28	Fisher Ridge Member (shale)	Goodville	inactive	crushed stone
29	Montebello Member, Mahantango Fm. (sandstone)	Lock Ridge	abandoned	building stone
30	Montebello Member (sandstone)	Wildcat Ridge	abandoned	building stone
31	Sherman Ridge Member, Mahantango Fm.	Raccoon Ridge	active	crushed stone
32	Sherman Ridge Mbr. (claystone)	Dimmsville	active	crushed stone
33	Sherman Ridge Mbr. (claystone)	Seven Stars	active	crushed stone

Table 32. (*Continued*)

(Locations are plotted on Plate 5)

Map no.	Formation or member	Location	Status	Product
34	Sherman Ridge Mbr. (claystone)	Kellerville	active	crushed stone
35	Sherman Ridge Mbr. (claystone)	Black Dog Valley	active	crushed stone
36	Sherman Ridge Mbr. (claystone)	Forrey Ridge	active	crushed stone
37	Sherman Ridge Mbr. (shale)	Forrey Ridge	inactive	crushed stone
38	Sherman Ridge Mbr. (shale)	Buckwheat Valley	inactive	crushed stone
39	Sherman Ridge Mbr. (shale)	Buckwheat Valley	inactive	crushed stone
40	Trimmers Rock-Harrell Fm. (shale)	Perry Valley	abandoned	crushed stone
41	Trimmers Rock-Harrell Fm. (shale)	Seven Stars	abandoned	crushed stone
42	Trimmers Rock-Harrell Fm. (shale)	Knousetown	inactive	crushed stone
43	Trimmers Rock-Harrell Fm. (shale)	East Salem	inactive	crushed stone
44	Trimmers Rock-Harrell (shale)	Buckwheat Run	abandoned	crushed stone
45	Trimmers Rock-Harrell (siltstone)	Black Dog Valley	abandoned	crushed stone
46	ish Valley Member, Catskill Fm.	Perry Valley	abandoned	crushed stone
47	IrSherman Creek Mbr., Catskill Fm. (silty claystone)	Oliver Twp.	inactive	crushed stone

cially produced lime, these private quarries have been abandoned. Small amounts of limestone have also been used as building stone.

One quarry (the Juniata Limestone Company quarry on Lost Creek Ridge, Fayette Township, Juniata County), continues to operate, producing crushed stone for road construction, concrete aggregate, and macadam. The beds extracted from this quarry (from the upper Tonoloway and lower Keyser) are described in Appendix I, locality 2 (Figures 18 and 19). A chemical analysis of a composite sample is given in Appendix II, which indicates an average calcium carbonate content of 85.55 percent, and a magnesium carbonate content of 0.29 percent.

CRUSHED STONE

Many of the roads in the quadrangle are light-duty "gravel" roads and several small quarries have been developed to supply material for their maintenance. These quarries are usually developed in weathered or partially weathered exposures (borrow pits) which can be easily worked with light equipment, and provide a gravel-size material without crushing or other processing. The Sherman Ridge Member of the Mahantango Formation is currently the principal unit being utilized, as at Kellerville. Material has also been taken from numerous, small borrow pits in the Fisher Ridge Member of the Mahantango Formation, the Marcellus Formation, the chert beds of the Old Port Formation, the Trimmers Rock Formation, and the Sherman Creek Member of the Catskill Formation. The siltstones and silty shales of these units pack well on the roads, drain well, and have a good resistance to washing out. None of the exposures are worked continuously, although a few are frequently reactivated (Figures 28 and 33).

A considerable amount of siltstone from the Trimmers Rock Formation is used on major highway construction projects in this area, most of it coming from a quarry at Newport (New Bloomfield quadrangle). There are several localities in the Millerstown quadrangle where this unit is well exposed and sufficiently thick, the lithology uniform, and the overburden thin enough that quarrying operations might be established in the future if there is a sufficient demand for this material.

CLAY SHALE

Although only one quarry has been developed in the quadrangle to extract shale for ceramic purposes (The Glen-Gery Corporation quarry in the Bloomsburg Formation south of Beavertown), the large amounts of shale present warranted an investigation of their potential ceramic uses. Thirteen samples were collected from seven stratigraphic horizons and tested by the U.S. Bureau of Mines for refractory properties (Table 33 and Appendix III). Three of the samples exhibited particular potential and were tested further.

The most promising unit is the Sherman Ridge Member of the Mahantango Formation, for which testing indicates an excellent potential as an expanded lightweight aggregate, as the sole component in most structural clay products (including sewer pipe), and as face brick and in the domestic stoneware industry. The lower 125 feet (38 m) of the Fisher Ridge Member of the Mahantango Formation was rated good for expanded lightweight aggregate, and could probably be used as a component in most structural clay products (including sewer pipe). The lower shaly member of the Rose Hill Formation is considered fair material for expanded lightweight aggregate, and could probably be used as the sole component in most structural clay products (including sewer pipe).

Table 33. *Results of Clay-Shale Tests on Samples from Millerstown Quadrangle*

(See Appendix III for sample locations.)

Sample no.	Formation	Type of material	Color Dry	Color Wet	Texture	Plasticity	Workability	Extruding properties	Water of plasticity (%)	% drying shrinkage	Dry strength	Drying properties	L.O.I.	pH	Electric conductivity
136-D-Sh-11[a]	Harrell	Shale	Light gray green	Dark green brown	Gritty	Poor	Short, mealy	Fair	16.6	2.3	83	Good	4.7	6.9	38
136-C-Sh/ Clyst-19[b]	Mahantango, Sherman Ridge Mbr.	Shale, clay	Dark gray	Black	Gritty	Fair	Fair	Excellent	18.6	1.8	97	Good	7.0	7.0	56
136-C-Sh/ Clyst-18[c]	Mahantango. Sherman Ridge Mbr.	Shale, clay	Med. gray brown	Brown black	Med. grit	Good	Good	Good	19.7	2.5	100	Good	5.8	7.9	21
136-A-Sh-8[d]	Mahantango, Sherman Ridge Mbr.	Shale	Med. gray yellow	Dark yellow brown	Med. grit	Good	Good	Good	20.7	3.3	134	Good	5.6	8.0	62
136-C-Sh-12[e]	Mahantango, Fisher Ridge Mbr.	Shale	Med. gray	Dark green brown	Gritty	Poor	Short, mealy	Poor	15.1	2.3	88	Fair, crumbly	4.1	7.8	22
136-C-Sh-20[f]	Marcellus	Shale	Light tan	Med. brown	Med. grit	Fair	Fair	Good	19.4	3.3	117	Good	4.6	8.4	18
136-C-Sh-13[g]	Marcellus	Shale	Dark gray	Black	Gritty	Fair	Short	Fair	20.0	2.5	153	Good	7.5	7.8	22
136-C-Sh-10[h]	Marcellus	Shale	Dark brown gray	Black	Gritty	None	Very short, mealy	Nonextrudable	17.6	2.5	Poor	Good, crumbly	10.2	7.3	37
136-A-Clyst-7[i]	Bloomsburg	Clay	Med. gray red	Dark red brown	Med. grit	Excellent	Excellent	Good	21.4	3.3	130	Good	7.1	9.0	81
136-C-Ls/ Sh-17[j]	Mifflintown	Limestone, shale	Light gray	Dark gray	Med. grit	Good	Good	Good	17.2	2.8	107	Good	21.8	9.6	176
136-C-Sh-16[k]	Rose Hill, upper shaly member	Shale	Med. gray	Dark gray	Gritty	None	Short, mealy	Nonextrudable	13.3	0.5	Poor	Good, crumbly	11.6	9.3	115
136-C-Sh-15[l]	Rose Hill, middle shaly member	Shale	Light gray brown	Dark brown	Gritty	Fair	Fatty	Good	15.9	3.0	117	Good	5.5	7.2	54

136-C-Sh-14[m]	Rose Hill, lower shaly member	Shale	Med. yellow	Med. yellow brown	Med. grit	Fair	Short	Fair	15.9	2.5	88	Good	5.6	8.1	21

	Comments	Potential uses
a	Good color range. Suggest the addition of a better bonding clay to improve plasticity and workability.	All structural clay products, floor tile, and architectural terra-cotta.
b	Good color range.	Sole component in most structural clay products and in the stoneware industry. Good color for face brick.
c	Good color range.	"Excellent" XLA*. Sole component in most structural clay products. Good color for face brick. Domestic stoneware industry.
d	Excellent color range. The addition of nonplastic grog would reduce shrinkage.	Sole component in most structural clay products (except sewer pipe unless total shrinkage is reduced). Probable use in art and industry.
e	Good color range. $CaCO_3$ (Qual.) positive. Suggest the addition of a better bonding clay to improve plasticity and workability.	"Good" XLA. Component in most structural clay products.
f	Suggest the addition of a better bonding material to improve plasticity and workability.	Component in most structural clay products.
g	Suggest the addition of a better bonding material to improve plasticity and workability.	Sole component in most structural clay products, decorative brick and architectural terra-cotta.
h		Domestic stoneware industry.
i		Possible use as nonplastic filler clay in some structural clay products.
		Sole component in most structural clay products, and porous clay products (such as flower pots). Domestic earthenware industry.
j	$CaCO_3$ (Qual.) extremely positive.	None in structural clay products. Possibly as a slip glaze at 2,300° F.
k	$CaCO_3$ (Qual.) positive.	Possible use as nonplastic component in some structural clay products.
l	Good color range.	Most structural clay products and porous clay products (such as flower pots). Possibly in artware industry.
m	Good color range. Suggest the addition of a better bonding material to improve plasticity and workability.	Sole component in most structural clay products. Possibly "fair" XLA.

*XLA—Expanded lightweight aggregate

BUILDING STONE

Stone buildings, many of them dating from the 19th century, are a common sight in the Millerstown quadrangle, particularly in Millerstown, Richfield, and Mount Pleasant Mills. The principal rock utilized for building construction is quartzite from the Tuscarora and Keefer Formations. Quarries have also been developed in the Montebello Member of the Mahantango Formation on Wildcat Ridge and Lock Ridge. In a few instances, limestone (apparently from the Tonoloway and Keyser Formations) has also been used as building stone. These rocks make very attractive and durable structures, and would be fairly inexpensive to obtain. Large areas on the slopes of Tuscarora and Shade Mountains are covered with quartzite boulders from the Tuscarora Formation. The rectilinear fracture pattern common in these quartzites enables the boulders to be used with a minimum of shaping. Thus production would involve primarily transporting the material from the slopes to the construction sites.

The utilization of building stone, and descriptions of several stone buildings in Juniata, Perry, and Snyder Counties, is discussed by Stone (1932).

QUARTZITE

The high-silica content of the quartzite beds in the Tuscarora Formation (93 percent, Appendix II) indicates that the quartzite has application in processes where high-silica material is required, as in the manufacture of silica brick. Currently, silica bricks are being produced from the Tuscarora Formation at Hawstone, northwest of Mifflintown. The Tuscarora quartzite is also suitable for use as railroad ballast, and was produced for this purpose at Millerstown during the construction of the Pennsylvania Railroad along the Juniata River (Claypole, 1885).

IRON ORE

Considerable extraction of sedimentary iron ore from the thin (12 to 14 inches, 37 to 43 cm) Sand-vein Ore Bed of the Keefer Formation in the Millerstown area developed after the Civil War, although the first mine (which supplied the Juniata Furnace) opened as early as 1844 (Claypole, 1885). The mines were located on Slaughterback Hill and Tuscarora Mountain near Millerstown, and on the flanks of Shade Mountain. The ore contains as much as 55 percent metallic iron (McCreath, 1881). It was shipped to Harrisburg, Reading, Dry Valley (Northumberland County), and via the Juniata Canal to Pittsburgh. This industry declined rapidly after the 1880's, principally because of competition from the newly discovered sources on the upper Great Lakes, and the destruction of the Juniata Canal by flooding.

By far the thickest and most plentiful iron occurs in the Center Member of the Rose Hill Formation. Swartz and Hambleton (1958) have estimated that more than 100 million tons of iron sandstone is present in this unit within 50 feet (15 m) of the surface in Perry County alone. But its low iron concentration (9 to 15 percent) has thus far precluded extensive development of the ore. The total iron content in samples from the Center Member at Millerstown is 8.19 percent and from the Cabin Hill Member, 10.43 percent. (Total iron content was calculated from iron oxide content given in Appendix II.) The Cabin Hill Member is 12.5 feet (4 m) thick and the Center Member is 79 feet (24 m) thick at Millerstown.

Other ferruginous horizons in the quadrangle, none of which are as rich as the Sand-vein Ore Bed (but some of which have been mined in the past) are the Boyer-block and Shot-block ores in the Rose Hill Formation (Figure 8), a concretionary limonite bed near the base of the Marcellus shale, a fossiliferous hematite bed near the top of the Montebello sandstone, thin, discontinuous, poor quality ferruginous zones in the Ridgeley sandstone of the Old Port Formation, and a four-inch (12-cm) seam of red specular hematite in the Catskill Formation (Claypole, 1885).

Descriptions of ferruginous sandstone units cropping out in the Millerstown quadrangle are contained in recent reports by Hunter (1960) and Luttrell (1968).

MISCELLANEOUS MINOR MINERAL OCCURRENCES

Minor amounts of fluorite (a colorless to deep purple calcium fluoride) have been found in veins of white calcite in the Tonoloway and Keyser Formations exposed in the Juniata Limestone Company quarry on Lost Creek Ridge just north of East Salem.

Wad (a mixture of several manganese oxide minerals) is ubiquitous as a thin film on fracture surfaces in the Sherman Ridge Member of the Mahantango Formation. Samples from the borrow pit at Kellerville contain a maximum MnO content of 0.12 percent (whole rock, Appendix II). The mineralogy and distribution of wad and other manganese minerals in Pennsylvania has been described by Foose (1945).

The Ridgeley sandstone of the Old Port Formation is quarried extensively for use as a glass sand in the Juniata River valley west of Lewistown, 15 miles (24 km) west of the Millerstown quadrangle. Although the Ridgeley is present in the quadrangle, it is thin and discontinuous and thus not particularly suitable for exploitation.

Uranium minerals have been reported from Precambrian, Devonian, Mississippian, and Triassic rocks in the central and northeastern parts of Pennsylvania (McCauley, 1961). The nearest reported uranium occurrences are in the Catskill Formation near Herndon (Millersburg quadrangle), and in the Catskill and Mauch Chunk Formations in Huntingdon County. The uranium minerals in the Catskill Formation occur as thin seams or lenses in gray to greenish-gray sandstones, and are usually associated with plant material and secondary copper minerals such as malachite and azurite. The radioactive minerals in the Mauch Chunk Formation occur in lenses of gray sandstone, siltstone, and claystone enclosed in red shale. A brief reconnaissance of similar rocks in these formations in the Millerstown quadrangle failed to detect any radioactivity greater than the normal background readings.

OIL AND GAS POTENTIAL

Oil and natural gas have been produced commercially in Pennsylvania since the drilling of the historic Drake well at Titusville in 1859. Most of this production has come from Upper Devonian sandstones and Lower Devonian Oriskany (Ridgeley) sandstone in the Allegheny Plateau northwest of the Valley and Ridge province. No oil production has yet been developed in the Valley and Ridge province itself. The nearest gas production in the Valley and Ridge occurs in the Artemus, Five Forks, and Purcell fields in Bedford County (75 miles, 120 km southwest of Millerstown) from faulted anticlinal reservoirs in the Ridgeley sandstone. Although a structural similarity exists between Bedford County and the Millerstown quadrangle, production from either the Upper Devonian sandstones or the Ridgeley is not likely in the quadrangle. The Upper Devonian is generally preserved only in the synclinal hinges in the Millerstown quadrangle, and appears to be devoid of both oil and gas. The Ridgeley sandstone is thin and discontinuous in this area, although zones of excellent porosity are locally present.

Judging from the wide stratigraphic range of oil and gas shows reported in four of the seven deep wells drilled in the vicinity of the quadrangle (Figures 98 and 99), more likely sources of oil or gas appear to be lower in the stratigraphic column. Gas shows were logged in the Silurian/Devonian Keyser limestone, the Silurian Bloomsburg Formation, the Ordovician Martinsburg, Trenton, Black River, and Beekmantown Formations, and the Cambrian Gatesburg dolomite. Oil shows were reported in two of these wells, producing from the Keyser limestone and the Ordovician Juniata and Bald Eagle Formations. The petroleum occurrences in the Ordovician formations are particularly interesting, since there has been no production from Ordovician rocks in Pennsylvania up to the present time.

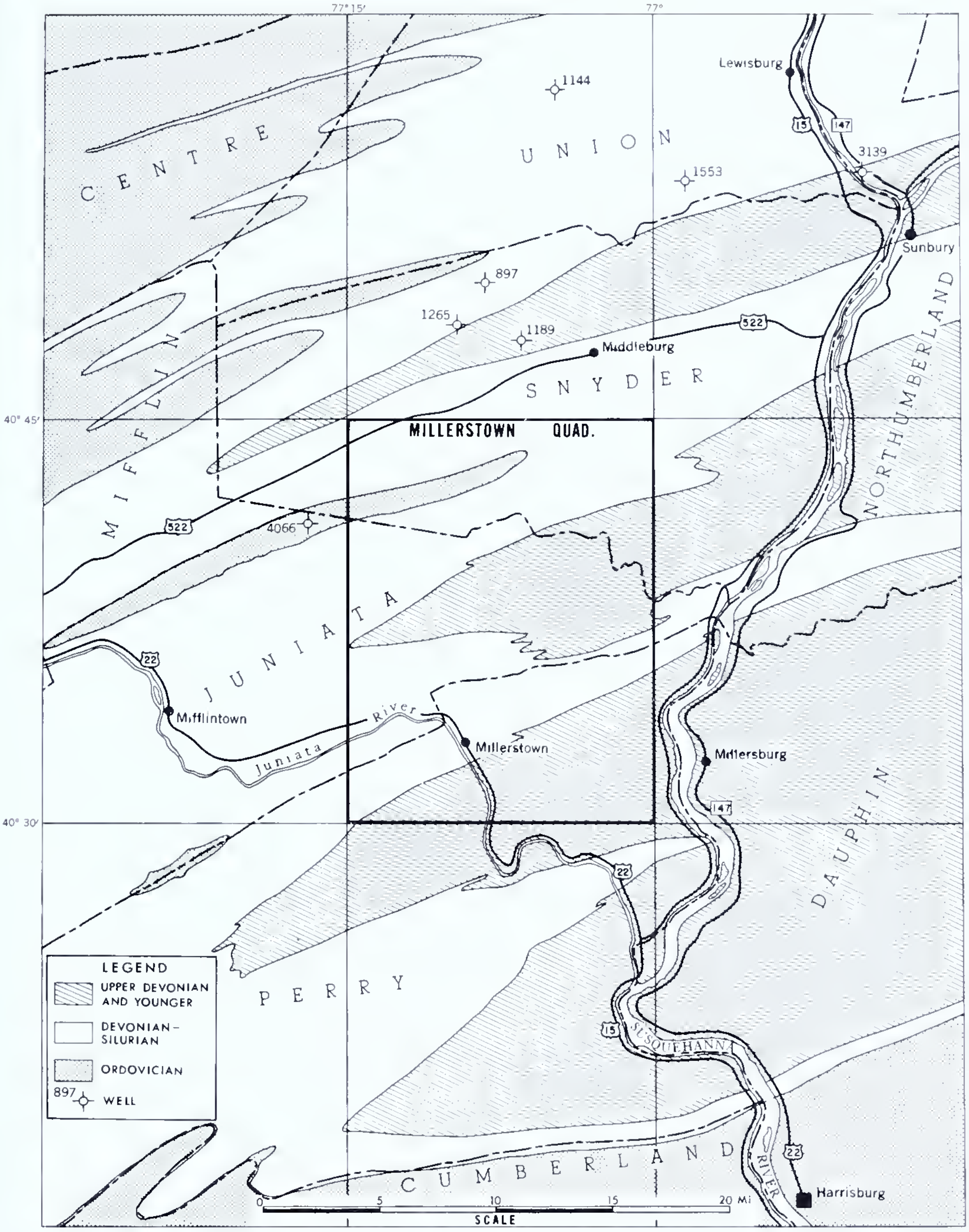


Figure 98. Location of exploratory wells in the vicinity of the Millerstown quadrangle. Pertinent data for these wells are presented in the Penetration Chart, Figure 99.

The oil and gas shows encountered in the Cabot #1 Solomon and the Shell #1 Shade Mountain Unit (wells 1553 and 4066, Figures 98 and 99), which were drilled on the hinges of major anticlines, suggest that anticlinal accumulations of petroleum might occur in the Cambrian or

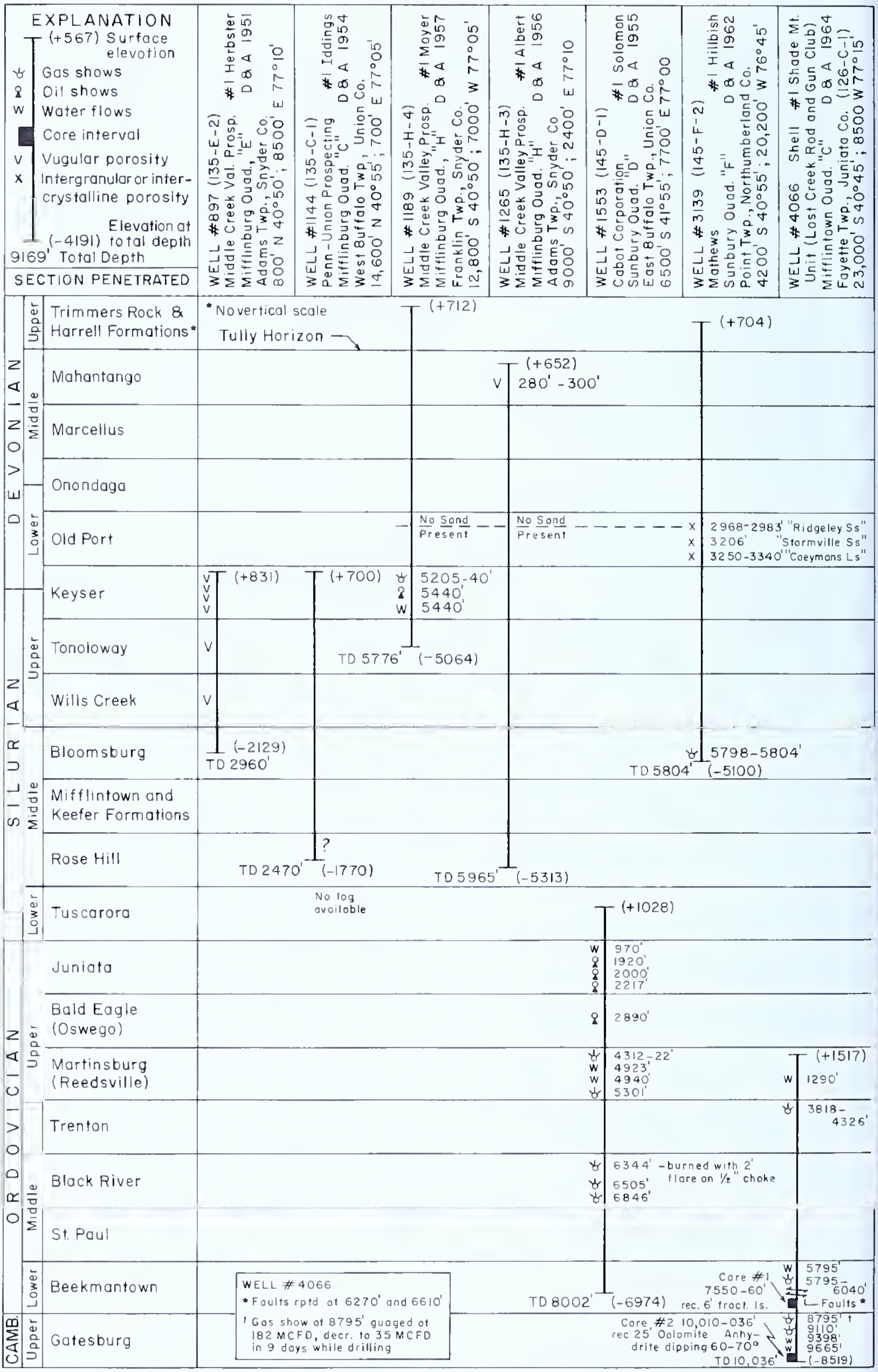


Figure 99. Penetration Chart, showing the stratigraphic section penetrated by exploratory wells drilled in the vicinity of the Millerstown quadrangle through June 1974, and the location of oil and gas shows and porosity zones.

Ordovician formations beneath Shade and Tuscarora Mountains. However, the faulting reported in the Shell well, as well as regional structural studies (e.g., Gwinn, 1964a, Rodgers, 1963), indicate that the structure may be different and more complex at depth than at the surface.

There has been no drilling for oil and gas in the Millerstown quadrangle to date, and no surface occurrences of petroleum have been reported.

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APPENDIX I. STRATIGRAPHIC SECTIONS

TERMS

Terminology for bedding thickness used in this report was adapted from McKee and Weir (1953) and Ingram (1954) with modifications. Beds designated very thin are less than one centimeter thick, thin beds range from one centimeter to two inches thick, medium beds ranges from two inches to two feet thick, thick beds are from two to four feet thick, and very thick beds are more than four feet thick. The term flat bedding refers to bedding surfaces which are essentially parallel and planar, i.e., not obviously crossbedded. The term tight is used to describe a rock which has a firm, compact texture and is essentially impermeable (Gary and others, 1972).

The term quartzite is used to describe sandstones (and in some instances siltstones) which are tightly cemented with silica, very tough and resistant, and break with an irregular fracture.

LOCALITY I. MILLERSTOWN SILURIAN SECTION

The Millerstown Silurian section was measured along the northbound lane of U.S. Route 22-322 in Millerstown Borough and Greenwood Township, Perry County, and in Delaware Township, Juniata County (Figure 100). The base of the section is 1.0 mile (1.7 km) northwest of the center of Millerstown in the lowest strata exposed on the crest of the Tuscarora Mountain anticline (Millerstown 7½-minute quadrangle). This point is approximately 100 feet (30 m) east of 77°10′ west longitude and 7,100 feet (2,164 m) north of 40°32′30″ north latitude. The top of the section is in the highest exposure of the Bloomsburg Formation 0.5 mile southeast of the junction of the Little Pfoutz Valley highway with U.S. Route 22-322, at a point 8,400 feet (2,560 m) west of 77°10′ west longitude and 9,000 feet (2,743 m) north of 40°32′30″. Thickness of units and proportions of intervals covered are summarized in Table 34.

This section is a composite of four segments measured in the four prominent roadcuts on the northeast side of U.S. Route 22-322 between Millerstown and Little Pfoutz Valley, as shown on the location map.

The strata exposed in the Millerstown Silurian section include the upper half of the Tuscarora Formation, the Rose Hill, Keefer, and Mifflintown Formations, and the lower 23 feet (7 m) of the Bloomsburg Formation. The portion of the Tuscarora Formation present in the measured section is 96 percent exposed. The Rose Hill Formation is 58 percent exposed, the covered intervals occurring exclusively in the lower and middle shaly members. The section above the Rose Hill Formation is 100 percent exposed. See Figures 4 through 14.

The Millerstown Silurian section lies on the crest and north limb of Tuscarora Mountain anticline, and the section crosses the structure at an angle of about 40° from the trend of the axis of the fold. Dips increase from less than 5° at the base of the section to 30° at the top.

The section was measured from the bottom to the top, and can be retraced in the following manner (see Figure 100). Beginning at the point on the crest of the structure mentioned above, the section offsets to the northwest eleven times in the Tuscarora Formation, then climbs the bed of a small intermittent stream on the southwest side of Slaughterback Hill to the point where the wooded area begins. Then the section may be traced northwest across the face of a broad, steep slope, offsetting on key beds wherever necessary. (This portion of the section was measured and sampled during the construction of the northbound lanes of U.S. Route 22-322, from a temporary terrace which has since been removed.) The base of the Rose Hill Formation is seven feet below the base of the lower of two fairly prominent greenish-gray sandstone ledges, and can be seen opposite power pole #98469, which is approximately 260 feet southeast of the post marking the Juniata/Perry County line. From this point the section extends upward to the top of unit 41, the (stratigraphically) highest exposure in this cut.

The second segment begins 0.3 mile northwest of the county line, at a culvert marked 428.43, and may be followed up the slope to the point of the second promontory (from the west) on the prominent sandstone ledge of the Cabin Hill Member.

The top of this member is used to offset across the small tributary valley to the west. The third portion of the section begins on top of the Cabin Hill Member at a point 160 feet east of the first culvert west of the tributary stream mentioned above and may be traced upwards, with several short offsets on appropriate beds, to the highest exposures on the hill. The top of this segment is two feet above the base of a prominent tall pine tree in a clearing 30 feet below the top of the hill.

The last segment of the Millerstown Silurian section begins in the middle shaly member of the Rose Hill Formation, at a point 95 feet southeast of the southernmost culvert in the next roadcut to the west. The section is uninterrupted above this point.

This section is intended as a reference section for these formations. The lithologic units are numbered consecutively beginning at the base of each formation and are herein described in descending order.

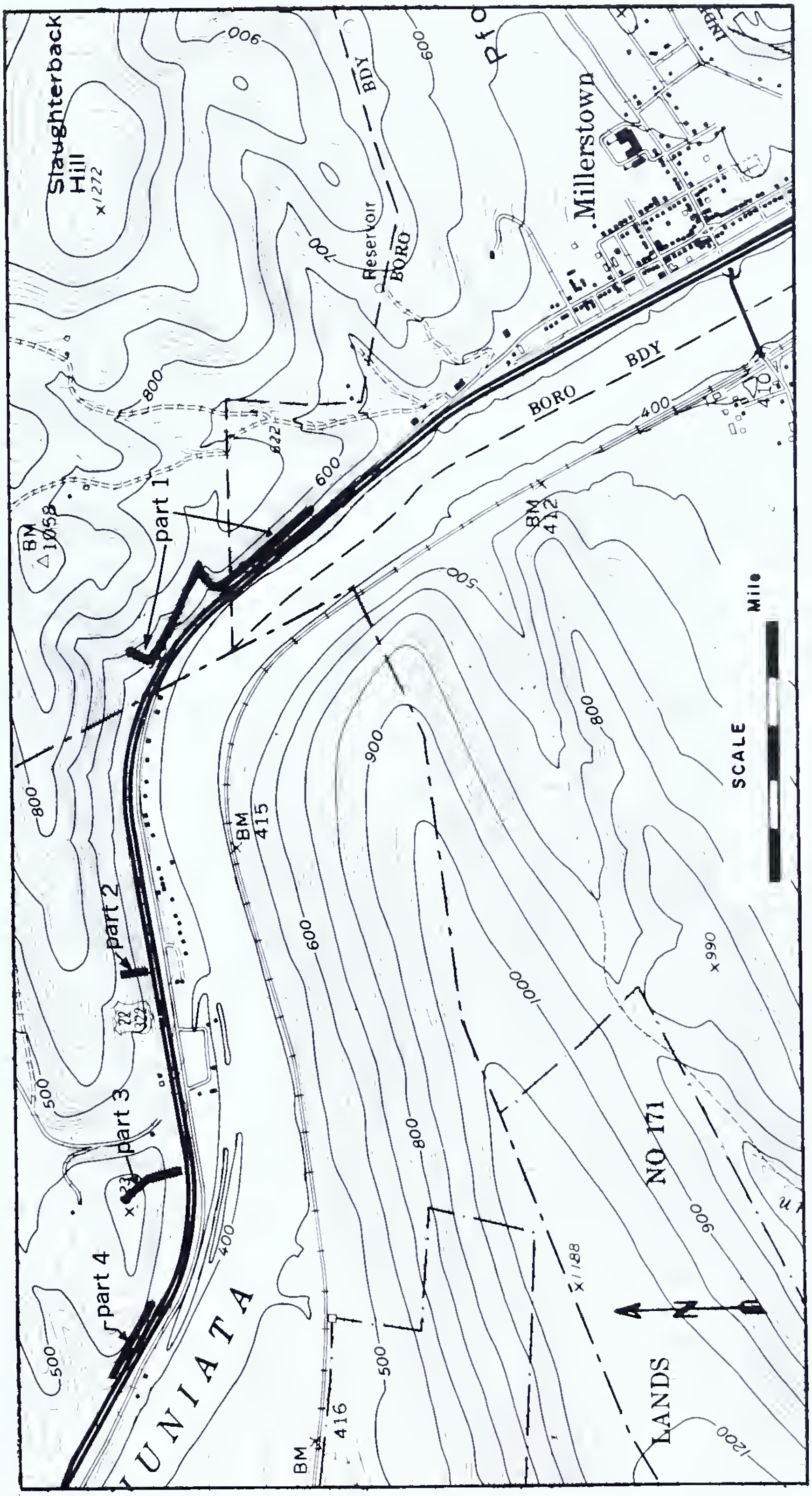

Figure 100. Location map, Millerstown Silurian section.

Table 34. *Summary of Measurements: Millerstown Silurian Section*

Units	Formation	Thickness (feet)	Thickness (meters)	Covered intervals (feet)	Covered intervals (meters)	Amount exposed
135–141	Bloomsburg Formation (partial)	23.0	7.0	none	none	100%
113–134	Mifflintown Formation	159.0	48.5	none	none	100%
103–112	Keefer Formation	38.0	11.6	none	none	100%
31–102	Rose Hill Formation					
95–102	Upper shaly member	116.0	35.4	none	none	100%
78–94	Center Member	79.0	24.1	none	none	100%
62–77	Middle shaly member	360.0	109.7	162.2	49.4	55%
61	Cabin Hill Member	12.5	3.8	none	none	100%
31–60	Lower shaly member	379.5	115.7	161.4	49.2	58%
	Total Rose Hill Formation	947.0	288.7	323.6	98.6	66%
1–30	Tuscarora Formation (partial)	270.0	82.3	12.9	3.9	95%
Total section:		1,437.0	438.1	336.5	102.5	77%

Upper Silurian

Bloomsburg Formation (23.0 feet (7 m)—partial)

Unit		*Thickness (feet)*
141	Covered. There is approximately 465 feet (141 m) of Bloomsburg Formation present above the highest exposure at this locality, based on isopach data from Hoskins (1961, pl. 8). *See Figure 13.*	
140	Shale, yellow-gray to dusky-yellow, mottled with grayish red (5Y8/1, 5Y6/4, and 5R4/2), very finely silty, waxy, locally hematitic, locally calcareous, soft and moderately fissile. Approximately 30 percent interbedded sandstone, similar to that in unit 139.	3.0
139	Sandstone, grayish-red (5R4/2), predominantly very fine grained, silty, locally fine grained, poorly sorted, argillaceous, noncalcareous, slightly friable, hematitic, locally slightly limonitic, medium- and thin-bedded, locally slightly porous.	8.0
138	Sandstone, grayish-red, locally grayish brown on joint surfaces (5R4/2 and 5YR3/2), very fine grained, silty, noncalcareous, hematitic, slightly limonitic, slightly siliceous, medium-bedded, planar-bedded, hard and tight.	1.0
137	Sandstone, grayish-red (5R4/2 to 10R4/2), predominantly very fine grained, locally fine grained to silty, argillaceous, hematitic, noncalcareous, medium- and thin-bedded, planar-bedded, medium-hard to slightly friable.	3.0
136	Sandstone, grayish-brown to dark-grayish-red (5YR3/2 to 5R3/2), very fine grained and silty, slightly siliceous, hematitic, medium- to thin- bedded, planar-bedded, hard, blocky fracture.	2.0
135	Sandstone, grayish-red (5R4/2 and 5R2/2), locally blackish red, fine- and very fine grained, locally argillaceous and silty, hematitic, noncalcareous, medium-bedded, irregularly flat bedded, medium-hard to slightly friable, locally slightly porous.	6.0

Mifflintown Formation (159 feet (48 m)—complete)

134	Shale, light-olive-gray to medium-olive-brown (5Y6/1 to 5Y4/4), generally slightly calcareous in lower half, slightly silty, becoming silty to very finely sandy and noncalcareous in upper half, subwaxy, moderately fissile, with occasional burrows and poorly preserved brachiopod shells.	14.0
133	Shale, medium-gray and medium-dark-gray (N5 and N4), calcareous, finely silty, poor to fair fissility, weathers light brown. Interbedded limestone, medium-gray (N5), fine- to medium-grained, bioclastic, silty, pyritic, in 3-inch beds in lower foot and at top, with local intraformational limestone breccia, and siltstone, light-gray, very calcareous, fossiliferous, pyritic, hard and tight, 3-inch bed 2 feet below top.	11.0
132	Limestone, medium-gray and medium-light-gray (N5 and N6), fine to coarse fragmental, locally oolitic, fossiliferous, hard and tight, 2 to 6 inches thick; has local intraformational limestone conglomerate. Interbedded shale, medium-gray (N5), calcareous, silty, poorly fissile.	2.0
131	Shale, medium-light-gray (N6), finely silty, locally calcareous, fairly fissile, dull to subwaxy luster, with interbedded limestone, medium-light-gray (N6), very fine grained, bioclastic, locally argillaceous and silty, slightly pyritic. Limestone comprises 30 percent of unit.	11.0

Unit		Thickness (feet)
130	Shale, medium-light-gray (N6), finely silty, locally calcareous, fairly fissile. *See Figure 14.*	2.0
129	Limestone, medium-dark-gray to dark-gray (N4 to N3), microcrystalline, locally pyritic, locally very silty, medium-bedded, with occasional oolites. Interbedded shale, dark-gray (N3), calcareous, slightly pyritic, silty, fair to poor fissility (30 percent of unit).	15.0
128	Shale, dark-gray (N3), calcareous, silty, with occasional siltstone laminae, and interbedded limestone, medium-gray and light-olive-gray (N5 and 5Y6/1), very silty, fine- to medium-grained, bioclastic, thin-bedded, planar-bedded, locally grading to calcareous siltstone. Unit is approximately 50 percent shale.	2.0
127	Limestone, dark-gray, weathers light olive gray (5Y6/1), microcrystalline and very fine grained, clastic, silty, locally argillaceous, with trace of finely disseminated pyrite, occasional oolites and fossiliferous zones. Irregularly medium bedded, with less than 10 percent interbedded shale, olive-black (5Y2/1), weathers light olive gray (5Y6/1), soft, fairly fissile, noncalcareous.	12.0
126	Limestone, dark-gray (N3), weathers olive gray (5Y4/1), very fine grained, clastic, locally bioclastic, silty, hard and tight, with 10 percent interbedded shale, light-olive-gray (5Y6/1), waxy, noncalcareous, in very thin (< 1 cm thick) beds between limestone layers. Microfossil zone at top.	2.0
125	Limestone, dark-gray (N3), weathers light olive gray (5Y6/1), fine- to very fine grained, bioclastic, slightly oolitic, locally coarse to medium crystalline, hard and tight. Underlain by 3-inch bed of soft moderate-brown calcareous clay. Top 3 inches of unit is shale, light-olive-gray (5Y6/1), silty, subwaxy, noncalcareous.	1.0
123	Interbedded shale (80 percent) and siltstone (20 percent). Shale is dark gray (N3), silty, calcareous, fairly to poorly fissile, highly fossiliferous in upper foot. Siltstone is medium dark gray (N4), calcareous, argillaceous, in irregular thin beds, locally grading to shale, slightly pyritic, locally very calcareous.	11.0
122	Shale, dark-gray and black (N1 to N3), silty, calcareous, poorly to fairly fissile, with occasional laminae of medium-dark-gray, calcareous, pyritic, argillaceous siltstone. Interbedded limestone, medium-dark-gray (N4), silty, micritic, slightly argillaceous and pyritic, medium-bedded, hard and tight, 40 percent of unit.	15.0
121	Shale, dark-gray to black (N3 to N1), calcareous, slightly silty, locally carbonaceous, with veins of white sparry calcite and laminae of medium-dark-gray (N4), calcareous, pyritic, argillaceous, ripple-marked siltstone. Shale is in part very soft, friable, and lignitic.	6.0
120	Interbedded limestone (70 percent) and shale (30 percent). Limestone is medium dark gray (N4), microcrystalline, silty, irregular to planar bedded, medium and thick bedded. Shale is dark gray (N3), calcareous, very finely silty, with occasional calcareous, fairly to poorly fissile, hard silt laminae.	8.0
119	Interbedded limestone (80 percent), shale (15 percent), and siltstone (5 percent). Limestone is dark gray (N3), micritic, partly argillaceous, partly silty, medium and thin bedded, flat bedded, tight. Shale is	

Unit		Thickness (feet)
	medium dark gray (N4), silty, generally very calcareous, poorly fissile, very finely micaceous. Siltstone is medium gray (N5), calcareous, locally very finely sandy, in occasional planar beds 1 inch thick.	11.0
118	Limestone, banded yellow-gray, medium-gray, and medium-dark-gray (5Y8/1, N5, and N4), silty, irregular thin beds. Interbedded shale, yellow-gray (5Y8/1), calcareous, silty, weathers to yellow-gray soil. Unit is 90 percent limestone.	1.0
117	Shale, medium-dark-gray (N4), calcareous, very finely silty, locally slightly micaceous, hard, poorly fissile, interbedded and gradational with siltstone, medium-gray (N5), argillaceous, calcareous, hard and tight, in irregular beds < 6 inches thick.	5.0
116	Limestone, medium-gray (N5), micritic to microcrystalline, locally fine to medium grained, bioclastic, slightly pyritic, thick-bedded, hard and tight.	3.0
115	Interbedded shale (80 percent), limestone (20 percent), and siltstone (trace). Shale is medium dark gray (N4), silty, calcareous, very finely micaceous, poorly fissile, hard. Limestone is medium gray (N5), very fine to medium grained, bioclastic, in part sandy to silty, slightly pyritic, hard and tight.	11.0
114	Shale, as above, with 10 to 15 percent interbedded limestone, medium-gray to medium-light-gray (N5 to N6), medium- to coarse-grained, bioclastic, silty to sandy, locally grading into very fine grained, calcareous, fossiliferous, crossbedded sandstone.	10.0
113	Shale, medium-dark-gray (N4), silty, very finely micaceous, poorly fissile, hard, with occasional mollusc shells. Unit includes 10 percent interbedded siltstone, medium-light-gray (N5), argillaceous, calcareous, locally very finely sandy, in slightly undulose beds 1 inch thick.	5.0
Keefer Formation (38 feet (12 m)—complete)		
112	Sandstone, mottled light-gray and dark-gray (N7 and N3), with heavy limonite staining increasing toward the top, becoming rusty yellow brown at top, predominantly fine grained, locally very fine to medium grained, poorly sorted, angular to subangular, locally slightly siliceous, crossbedded, medium-bedded, fair to locally good porosity. Unit includes two 1-inch, medium-dark-gray (N4), noncalcareous, silty, poorly fissile shale beds in lower foot. *See Figure 12.*	10.0
111	Sandstone, mottled medium-light-gray and medium-dark-gray (N6 and N4), limonitic in upper 2 inches, predominantly very fine and fine grained, locally very fine to medium grained, silty, locally argillaceous, siliceous, noncalcareous, fossiliferous. Tight in lower part, becoming fairly porous in top 2 feet due to decrease in cement and upward increase in grain size and sorting. Massive, with trace of obscure crossbedding. Fossil material includes crinoids and molluscs. One-inch bed of soft, medium-gray, waxy clay at base.	5.0
110	Interbedded sandstone and shale. Sandstone is medium light gray to light gray (N6 to N7), very fine grained, silty, siliceous, very hard and tight, thin and very thin bedded, ripple marked. Shale is medium dark gray (N4), silty, noncalcareous, similar to basal part of unit 108.	0.5

Unit		*Thickness (feet)*
109	Sandstone, dark-gray (N3), locally blackish red (5R2/2), very fine to medium-grained, predominantly fine grained, silty, generally calcareous, siliceous, argillaceous graywacke. Occasional oolitic hematite zones. Top one foot is thin bedded with interbedded medium-dark-gray (N4), silty, noncalcareous shale.	7.5
108	Sandstone, medium-light-gray (N6), very fine to coarse-grained, slightly calcareous, locally argillaceous and silty, medium- to very thin bedded, with irregular ripples and burrows, contorted bedding. Interbedded shale, medium-dark-gray to dark-gray (N4 to N3), noncalcareous, silty.	2.0
107	Interbedded sandstone (60 percent) and shale (40 percent). Sandstone is medium light gray (N6), very fine and fine grained, has occasional coarse to very coarse, angular quartz grains, is slightly calcareous, thin to very thin bedded, hard and tight. Shale is medium dark gray (N4 to N3), silty, locally sandy, hard, poorly fissile, noncalcareous, locally carbonaceous, ripple marked and burrowed. Interference ripple marks.	7.0
106	Sandstone, mottled light-gray and medium-dark-gray (N7 to N4), very fine to coarse-grained, partly silty, partly argillaceous, generally calcareous, massive, highly burrowed.	1.0
105	Shale, medium-dark-gray (N4), silty, noncalcareous, hard, poorly fissile, with laminae of siltstone, medium-light-gray (N6), very finely sandy, locally calcareous, pyritic; flaser bedding.	3.0
104	Sandstone, medium-light-gray (N6), very fine grained, silty, slightly calcareous, with local argillaceous streaks, thin-bedded, rippled; has laminae of medium-dark-gray noncalcareous shale.	1.0
103	Sandstone, medium-light-gray (N6), transitional from coarse-grained sandy limestone at base to calcareous sandstone at top; very thin bedded, crossbedded, tight, with laminae of medium-dark-gray (N4), noncalcareous shale.	1.0
Rose Hill Formation (943 feet (287 m)—complete) *Upper shaly member* (116 feet (35 m)—complete)		
102	Shale, medium-dark-gray (N4), locally dark gray (N3), silty, noncalcareous, dull to subwaxy, poorly fissile, hard, slightly carbonaceous near top, with interbedded sandstone in top foot. Sandstone is medium light gray (N6), very fine grained, silty, calcareous, pyritic, hard, in beds and laminae less than one inch thick, irregularly bedded; current ripple marks. Sandstone comprises 50 percent of top one foot of unit.	10.0
101	Interbedded limestone (40 percent), shale (40 percent), and calcareous siltstone (20 percent) in cyclic repetition. Limestone is medium gray to medium dark gray (N5 to N4), locally grayish black (N2), bioclastic, pyritic, tight, with lenses of crossbedded calcarenite. Siltstone is medium gray (N5), locally medium dark gray (N4), generally calcareous, with current ripple marks; generally gradational with underlying fossiliferous limestone. Shale is medium dark gray and dark gray (N4 and N5), silty, very finely micaceous, noncalcareous, fairly to poorly fissile, hard, with interbedded laminae of gray, silty, pyritic limestone.	12.0

Unit		*Thickness (feet)*
100	Shale, medium-dark-gray (N4), silty, slightly calcareous, hard, fairly to poorly fissile. Interbedded limestone (<5 percent of unit), medium-gray (N5), bioclastic, silty, pyritic, hard and tight, in occasional 2-inch beds. Unit includes a trace of siltstone, medium-gray (N5), slightly calcareous, hard and tight, planar-bedded, in occasional 1- to 2-inch beds in top half of unit.	12.0
99	Limestone, medium-gray (N5), bioclastic, massive, very fossiliferous, silty, possibly slightly argillaceous, hard and tight.	3.0
98	Predominantly limestone (90 percent) with interbedded shale and siltstone (10 percent.) Limestone is medium light gray (N6), weathers light tan, is bioclastic, fossiliferous, medium bedded, flat bedded. Fauna includes pelecypods, brachiopods, and trilobites. Shale is medium dark gray (N4), very finely silty, slightly micaceous, noncalcareous, poorly fissile. Siltstone is medium gray (N5), calcareous, crossbedded, hard and tight, in a single 3-inch bed 1 foot below top.	7.0
97	Interbedded limestone (60 percent), siltstone (20 percent), and shale (20 percent). Limestone is medium gray (N5), bioclastic; planar beds <6 inches thick grade upwards into silty limestone and calcareous siltstone. Siltstone is medium gray (N5), calcareous, locally very pyritic, in planar beds 6 inches thick. Shale is medium gray and grayish red purple (N5 and 5RP4/2), micaceous, slightly calcareous, very finely silty in streaks, poorly fissile, locally grading to claystone. *Culvert in unit 97 is marked with the elevation 436.03.*	36.0
96	Interbedded shale (70 percent), limestone (25 percent), and siltstone (5 percent). *See Figure 9*. Shale is medium dark gray to dark greenish gray (N4 to 5GY4/1), noncalcareous, very finely silty, slightly micaceous, fairly to poorly fissile. Limestone is medium gray (N5), bioclastic, microcrystalline, locally coarsely crystalline, thin (3-6 inches thick) bedded, planar bedded, fossiliferous. Fauna predominantly brachiopods and pelecypods. Siltstone is medium gray (N5), very slightly calcareous, in irregular to planar beds 2 to 6 inches thick, having flat, sharp bases, irregular tops, and ripple marks.	8.0
95	Predominantly shale (90 percent) with interbedded sandstone and limestone. Shale is brownish gray and medium gray with pale reddish cast (5YR4/1, N5, 5R4/2), slightly silty. Sandstone is medium dark gray (N4), very fine grained, calcareous, hard and tight, in planar beds 1 inch thick. Limestone is medium dark gray (N4), microcrystalline, bioclastic, locally sandy, fossiliferous, hard and tight. Prominent sandstone bed 15 feet above base, slightly reddish medium dark gray, very fine grained, hematitic, hard and tight, 3 to 9 inches thick; scour-and-fill deposit with convex base and flat top.	28.0
	Center Member (upper "iron sandstone") (79 feet (24 m)—complete)	
94	Sandstone, medium-dark-gray to blackish-red (N4 to 5R2/2), very fine grained, locally fine grained, hematitic, thin- and medium-bedded (1 cm to 2 feet thick), hard and tight, with ripple marks and greenish-gray (5GY6/1) shale partings.	5.0
93	Shale, medium-gray, greenish-gray, and blackish-red (N5, 5GY6/1, 5R2/2), poorly fissile, hard, with lenses, laminae, and burrow casts of sandstone, medium-dark-gray, greenish-gray, and reddish-black (N4, 5GY6/1, 5R2/2), very fine grained, silty, hematitic, hard and tight.	8.0

Unit		*Thickness (feet)*
92	Sandstone, medium-dark-gray (N4), very fine grained, hematitic, in a single bed which thins from 1.5 feet to 3 inches in a lateral distance of 50 feet.	1.0
91	Interbedded sandstone (80 percent) and shale (20 percent). Sandstone is medium gray to blackish red (N4 to 5R2/2), very fine grained, silty, hematitic, thin and medium bedded, has blocky fracture. Approximately 20 percent interbedded shale, medium-gray (N5) to greenish-gray (5GY6/1), fairly hard, poorly fissile, very finely silty, slightly micaceous.	5.0
90	Shale, medium-gray, dark-greenish-gray, and grayish-red (N5, 5GY4/1, 5R4/2), very finely silty, poorly fissile, with laminae, lenses, and burrow casts of sandstone, medium-gray to dark-gray (N5 to N3), fine- and very fine grained, silty, hematitic, hard and tight. Prominent 2-inch blackish-red to reddish-black, very coarse grained sandstone bed 2 feet above base, with generally well rounded rose and smoky quartz sand in a matrix of very fine grained hematitic sand. Ripple marks common throughout unit.	8.0
89	Sandstone, dusky-brown (5YR2/2) to very dusky red (10R2/2), very fine grained, hematitic, medium-bedded, planar-bedded, very hard and tight.	1.0
88	Sandstone, dark-grayish-red (5R4/2), very fine grained, hematitic, locally limonitic, thin-bedded, flat-bedded. Interbedded shale, dark-grayish-red and greenish-gray (5R4/2 and 5GY6/1), hematitic, sandy, highly burrowed.	2.0
87	Sandstone, as above, with scattered dark-grayish-red (5R4/2) shale clasts and few greenish-gray (5GY6/1) shale partings. Medium bedded.	2.0
86	Sandstone, dark-reddish-gray, very fine grained, silty, hematitic, thin-bedded, with very dark grayish red shale partings.	2.0
85	Shale and claystone, medium-dark-gray (N4) to greenish-gray, sandy, with lenses of very fine to fine-grained sandstone in irregular beds 1 to 4 inches thick; ripple marked.	2.0
84	Sandstone, dark-reddish-gray, very fine grained, silty, hematitic, slightly siliceous, hard and tight, with sharp vertical fractures; discontinuous beds 1 to 6 inches thick; local light-greenish-gray streaks, dark-reddish-gray clay clasts, and dark-gray shale interbeds.	3.0
83	Shale, dark-greenish-gray (5G4/1) becoming grayish red in top foot. Interbedded sandstone, medium-gray (N5), fine- and very fine grained, in discontinuous lenses and streaks; flaser structure.	2.0
82	Claystone, medium-gray (N5), silty, locally sandy, with lenses of medium-gray sandstone generally < ¼ inch thick, locally 1 inch thick.	7.0
81	Interbedded sandstone (70 percent) and siltstone (30 percent). Sandstone is dark grayish red (5R4/2), very fine grained, argillaceous, hematitic, irregularly bedded. Siltstone is dark grayish red (5R4/2), weathers orange brown, sandy, hematitic, in planar beds 1 to 4 inches thick, has blocky appearance due to vertical fractures.	6.0
80	Sandstone, dark-grayish-red (5R4/2), predominantly very fine grained, locally fine grained, hematitic, locally yellow brown, limonitic, irregularly thin and medium bedded, ripple-marked and burrowed, with dark-grayish-red shale partings and interbeds.	10.0

Unit		*Thickness (feet)*
79	Interbedded shale (80 percent) and sandstone. Shale is reddish gray, slightly silty, with thin lenses and pods of grayish-green, fine- to very fine grained sandstone. Sandstone is dark grayish red, locally mottled grayish green, very fine grained, silty, hematitic, burrowed, in planar beds 1 to 4 inches thick. Gradational contact with overlying shaly sandstone.	8.0
78	Sandstone, dark-grayish-red (5R4/2), very fine grained, very silty, locally becoming hematitic, thin- and medium-bedded, ripple-marked, sandy siltstone with thin clay laminae at base of each bed. Bedding locally contorted, with variety of trails and burrows.	7.0
	Middle shaly member (360 feet (110 m)—complete)	
77	Shale, medium-dark-gray in lower half, reddish-medium-dark-gray mottled with greenish gray (5GY6/1) in upper half, becoming greenish gray in upper foot, generally pure, locally silty, with thin discontinuous lenses of medium-dark-gray siltstone and silty sandstone, slightly siliceous, hard and tight.	6.0
76	Interbedded shale (95 percent), siltstone (5 percent), and sandstone (trace). Shale is olive gray, locally grayish red, medium hard, fairly to poorly fissile, silty, noncalcareous. Siltstone is medium dark gray to olive gray, slightly siliceous, locally slightly calcareous, thin bedded, flat bedded, with thin laminae of dark-gray clay. Siltstone locally becomes medium bluish gray (5B5/1) and very finely sandy. Sandstone is in a single bed 15 feet above base, ½ inch thick, medium gray, very fine grained, slightly silty, siliceous, noncalcareous, flat bedded, hard and tight.	31.5
75	Siltstone, olive-gray (5Y4/1), sandy, slightly calcareous, siliceous, hematitic, with approximately 40 percent very fine grained, siliceous, hard and tight sandstone in alternating laminae.	0.5
74	Covered. *Offset 0.35 mile (0.58 km) northwest along northeast side of U.S. Route 22-322.*	13.0
73	Seventy-five percent covered. Exposed beds are 90 percent siltstone, 10 percent shale. Siltstone is grayish orange (10YR6/4 to 10YR7/4) to light brown (5YR5/6), coloration due to limonite staining on weathered samples, fresh rock color not seen here. Siltstone is siliceous, slightly argillaceous, noncalcareous, slightly to fairly porous, hard and resistant, medium and thin bedded (<6 inches thick), planar bedded. Shale is dark yellow orange (10YR6/6) and grayish orange (10YR7/4) to light brown (5YR5/6), silty, poorly fissile, noncalcareous, splintery, locally fossiliferous (ostracods).	43.0
	Top of unit 73 is 2 feet above base of tall pine in clearing approximately 30 feet vertically below crest of hill. Top of hill is covered, but float on crest includes fragments of Center Member.	
72	Shale, predominantly olive brown (5Y4/6 and 5Y5/6), variable light-olive-gray (5Y5/2) to yellow-brown (10YR5/2), generally slightly silty, moderately fissile, rarely very silty. Unit includes trace of fossiliferous siltstone, 1 mm thick, 8 feet above base, and ostracod zone 74 feet above base. Seventy-five percent covered.	98.0
71	Shale, predominantly yellow brown (10YR4/2), silty, hard, poorly fissile, very thin bedded, poorly exposed, 90 percent covered.	11.0

Unit		*Thickness (feet)*
70	Shale, predominantly yellow brown (10YR4/2), locally moderate brown (5YR4/4), pale brown (5YR5/2), and light olive gray (5Y5/2), slightly silty, locally very silty, fairly to poorly fissile, thin-bedded, locally fossiliferous. Poorly preserved crinoid columnals 19 feet above base and small pelecypods 10 feet below top. Few thin interbeds of siltstone, medium-brown (5YR5/4), slightly argillaceous, slightly porous, locally fossiliferous, containing occasional disarticulated and abraded shell fragments. Unit is 80 percent covered.	27.0
69	Shale, gray-brown (5YR3/2 to 5YR4/2) and moderate-brown (5YR3/4), weathers dark yellow brown (10YR4/2), thin bedded, very slightly silty, poorly to fairly fissile, hard, subwaxy, noncalcareous, locally fossiliferous, containing ostracods and possible thin crinoid columnals. Interbedded siltstone (1 to 2 percent of exposure), light-olive-gray (5Y5/2 and 5Y6/2), slightly argillaceous, slightly porous, noncalcareous, in scattered planar beds ½ inch thick.	34.0
	Top of unit 69 is at top of cut bank, at tree line on highest part of roadcut.	
68	Shale, olive-gray to yellow-gray (5Y5/2 to 5Y7/2), locally light olive brown (5Y5/6), slightly to very silty, locally micaceous, generally subwaxy, hard, fairly fissile, with occasional silty laminae near top.	26.0
67	Siltstone, light-olive-gray (5Y5/2 to 5Y6/2), slightly siliceous, slightly argillaceous, noncalcareous, thin-bedded, flat-bedded, slightly porous, with local limonite staining.	5.0
66	Shale, light-olive-gray to yellow-gray (5Y4/2 to 5Y7/2), generally pure, locally moderately silty, fairly fissile, subwaxy, thin-bedded, planar-bedded, locally burrowed.	32.0
65	Covered.	12.0
64	Interbedded sandstone (50 percent) and shale (50 percent). Sandstone is grayish red (10R4/2 to 5R4/2), very fine grained, with scattered fine and medium quartz grains; hematitic, siliceous, argillaceous. Very hard and tight, ripple marked and burrowed. Intercalated shale is light olive gray and grayish red (5Y5/2 and 5R4/2), slightly silty, in part hematitic.	3.0
63	Siltstone, light-olive-gray (5Y5/2), mottled with medium gray (N4), argillaceous, slightly siliceous, irregularly very thin bedded, ripple-marked, highly burrowed, with irregular laminae and lenses of light olive gray as in unit 62.	9.0
62	Interbedded shale (75 percent), siltstone (20 percent), iron sandstone, and quartzite (5 percent). Shale is light olive gray (5Y4/2 and 5Y5/2), and yellow gray (5Y5/4 to 5Y7/2), very finely silty, locally hematitic, subwaxy, thin bedded, fairly fissile, splintery, with burrows, flasers, lenses and laminae of gray siltstone. Siltstone is light olive gray (5Y5/2) and medium light gray (N6), siliceous, locally very finely sandy, slightly argillaceous, hard and tight, in thin and very thin discontinuous beds and lenses. Locally grades to quartzite. Sandstone is grayish red (5R3/2 to 5R4/2), very fine grained, silty, hematitic, siliceous, locally limonitic. Occurs as one-inch beds ½ and 2½ inches above base, and one 4-inch bed 2 feet below top.	9.0
	Section offsets across stream valley on top of Cabin Hill Member.	

Unit		*Thickness (feet)*
	Cabin Hill Member (12.5 feet (4 m)—complete)	
61	Sandstone, blackish-red (5R2/2 to 5R3/2), very fine grained, hematitic matrix, limonitic, with limonite filling fine vugs, medium- and thin-bedded (< 1 inch thick), irregular bedding with scour-and-fill structure, trough-type crossbedding, and poorly developed ripple marks. Hematite locally becomes specular, pisolitic. Grayish-red shale pebbles scattered throughout unit. Interbedded shale (approximately 10 percent of unit), grayish-red (5R4/2), silty, hematitic, generally poorly fissile, in irregular and discontinuous lenses and laminae. Unit forms prominent cliff.	12.5
	Lower shaly member (379.5 feet (114 m)—complete)	
60	Interbedded shale (80 percent) and siltstone (20 percent). Shale is yellow brown (5Y5/4), pure to very finely silty, has fair to good fissility. Siltstone is light olive gray (5Y5/2), slightly argillaceous, slightly siliceous, noncalcareous, thin bedded, tight. In upper 3 feet both shale and siltstone become slightly hematitic and limonitic; contact with overlying Cabin Hill Member is gradational.	6.5
59	Covered.	4.0
58	Interbedded siltstone (50 percent) and shale (50 percent). Siltstone is light olive gray (5Y5/2), slightly siliceous and argillaceous, thin and very thin bedded, burrowed and ripple marked. Shale is light gray brown (5YR4/2), becoming gray brown to grayish red (5YR3/2 to 5R4/2), silty, fairly to poorly fissile, with silt laminae and siltstone-filled burrows.	14.0
57	Predominantly shale (80 percent), with interbedded sandstone and quartzite. Shale is light grayish brown (5YR4/2), very finely silty, has dull luster, is thin bedded, fairly fissile. Quartzite is medium light gray (N6) to light olive gray (5Y5/2), very fine grained, silty, in thin and very thin beds and discontinuous lenses, locally ripple marked. Sandstone is grayish black, very fine grained, siliceous, hematitic, slightly limonitic, low-grade "iron sandstone." One 3-inch bed at top of unit.	3.0
56	Interbedded quartzite (60 percent), siltstone (30 percent), and shale. Quartzite is medium light gray (N6), very fine grained, silty, slightly hematitic, generally thin bedded (1 to 3 inches thick), ripple marked. Siltstone is light olive gray (5Y5/2), finely silty, fairly fissile, thin bedded, with poorly preserved ripple marks.	1.0
55	Siltstone, light-olive-gray to olive-gray (5Y5/2 to 5Y3/2), slightly siliceous, argillaceous, thin-bedded, tight, locally ripple marked. Forty percent interbedded shale, yellow-brown (5Y5/4) very finely silty, fair to good fissility, with lenses and burrow casts of siltstone, as above.	8.0
54	Siltstone, yellow-brown (5Y5/4), very finely sandy, siliceous, argillaceous, thin-bedded, ripple-marked.	3.0
53	Shale, moderate-olive-brown to grayish-olive (5Y4/4 to 10Y4/2), very finely silty, fairly fissile, burrow casts and lenses of siltstone, light-olive-gray (5Y5/2), slightly argillaceous, siliceous (< 10 percent of unit). Siltstone beds are < 1 inch thick, ripple marked.	22.0

Unit		*Thickness (feet)*
52	Shale, as above, with 1-foot bed of quartzite at top. Quartzite is medium gray (N5 to N6), very fine grained, possibly silty, medium bedded, planar bedded, very hard and tight. Unit 10 to 20 percent covered.	4.0
51	Interbedded quartzite (20 percent), iron sandstone (20 percent), and shale (10 percent). Unit is 50 percent covered. Quartzite is medium gray (N5), very fine grained, hard and tight, medium bedded, ripple marked. Iron sandstone is dark gray (N3 to N4), very fine grained, siliceous, hematitic, slightly limonitic, medium bedded, poorly exposed. Shale is grayish olive (10Y4/2), waxy, fissile, soft. Thickness of unit may be exaggerated due to slumping.	5.0
50	Covered. Float is shale, moderate-olive-brown to light-olive-gray (5Y4/4 to 5Y5/2), very finely silty, subwaxy, fairly fissile, with occasional siltstone burrow casts. A few exposures reveal bedrock similar to float.	5.5
49	Quartzite, medium-gray (N5), fine- to very fine grained, hard and generally tight, but locally slightly porous.	0.5
48	Shale, grayish-olive to light-olive-gray (5Y5/2 to 10Y4/2), slightly to very silty, slightly siliceous, noncalcareous, fairly fissile, splintery, with laminae and lenses of olive-gray, siliceous, tight siltstone. Interbedded siltstone, medium-light-gray (N6), siliceous, thin- and very thin bedded, irregularly bedded, very hard and tight.	14.0
47	Shale, moderate-olive-brown to grayish-olive (5Y4/4 to 10Y4/2), very finely silty, thin-bedded, fairly fissile, ripple-marked, burrowed, with thin lenses and burrow casts of siliceous siltstone. In upper 4 feet shale becomes siltier, more siliceous, poorly fissile, and blocky. Unit contains two beds of iron sandstone, black, very fine grained, hematitic, very hard and tight, locally resembling specular hematite; 1-inch bed 8½ feet above base and 6-inch bed at top.	11.5
46	Interbedded shale (50 percent) and quartzite. Shale is medium gray (N5), locally greenish gray to dark greenish gray (5G4/1 to 5G6/1), very finely silty, subwaxy, with occasional thin beds of medium-gray (N5), siliceous, tight, rippled and burrowed siltstone. Quartzite is medium gray (N5 to N6), very fine grained, silty, weathers to rusty brown, in irregular beds 6 to 12 inches thick, locally nodular. Unit includes 2-inch beds of black (N1) specular hematite at top, with limonite vugs in weathered zone.	6.5
45	Shale, predominantly medium gray (N6), with slight greenish cast, locally becoming dark greenish gray (5G4/1), very finely silty, subwaxy, fairly fissile, thin-bedded, with <5 percent interbedded quartzite. Quartzite is medium gray (N5), locally brownish gray (5YR4/1), very fine grained, silty, very hard and tight, occurs as occasional planar to slightly irregular beds <2 inches thick.	13.0
44	Quartzite, medium-gray (N5), very fine grained, silty, very hard and tight, forms one irregular bed which varies in thickness from ½ to 2 feet due to load casting at base. Spheroidal weathering.	2.0
43	Siltstone, greenish-gray (5GY6/1), locally medium gray (N5), and brownish gray (5YR4/1), siliceous, slightly argillaceous, locally slightly hematitic, thin- and very thin bedded, very hard and tight, burrowed, rippled. Interlaminated shale, greenish-gray, very finely silty, subwaxy, fairly fissile.	4.0

Unit		*Thickness (feet)*
42	Covered.	132.0
	Section is offset along northeast side of the northbound lane of U.S. Route 22-322 in unit 42. Units 43 through 61 are measured in cutbank above culvert no. 428.43.	
41	Shale, olive-gray, locally light olive brown, waxy, locally very finely silty, approximately 10 percent covered.	48.0
40	Covered.	3.0
39	Siltstone, medium-light-gray, argillaceous, locally slightly fissile, generally hard and siliceous.	4.0
38	Siltstone, light-gray to medium-light-gray, argillaceous, locally slightly sandy, in gradational contact with underlying shale. *Forms highest prominent ledge on cutbank.*	3.0
37	Shale, light-olive-gray, subwaxy, fairly fissile, with occasional 1-inch beds of olive-gray to buff siliceous siltstone ($<$ 10 percent of unit).	9.0
36	Interbedded siltstone (80 percent), shale (10 percent), and sandstone (10 percent). Siltstone is greenish gray, locally grading to medium gray, argillaceous, locally becomes silty claystone. Becomes grayish red purple (5RP4/2) and hematitic toward top of unit. Shale is medium gray, very finely sandy, locally grading to shaly sandstone. Sandstone is medium gray, very fine grained, argillaceous, siliceous; texture obscured by cement. Gradational with argillaceous siltstone above. *This sandstone is informally called the "upper green sandstone" of the Tuscarora/Rose Hill contact zone. Top of unit forms second highest prominent ledge on cutbank.*	11.0
35	Covered. Float is greenish-gray (5GY6/1) sandstone and grayish-red-purple (5RP4/2), argillaceous, sandy siltstone, locally mottled greenish gray. Appears to be nearly in place.	9.0
34	Interbedded sandstone (20 percent), and shale (80 percent). Sandstone is light gray, weathers very light gray, is fine and medium grained, locally coarse grained, pyritic, medium bedded, with occasional shale clasts ($<$ 1 inch wide) of dark-gray silty clay. Occasional ripple marks, small-scale load casts, and channel scours. Prominent channel scour 12 feet above base is filled with sandstone, white to light-gray, fine- and medium-grained, siliceous, very thin to medium-bedded, with dark-gray clay pebbles and shale laminae near base. Shale is dark gray (N3), locally silty to sandy, with laminae, lenses, and burrow casts of light-gray fine to medium sand.	22.0
	(The interbedded sandstones and shales of Rose Hill unit 34 are similar to the upper strata of the underlying Tuscarora Formation, the principal distinction being the slightly lighter colored sandstones and darker colored shales in unit 34, and a greater amount of crossbedding in the Tuscarora. Also, the shales of the lower part of the Rose Hill are not sandy, generally not very silty, have no sand laminae, and have a better fissility than the shales in the top of the Tuscarora Formation.)	
33	Sandstone, greenish-gray, very fine grained, argillaceous, locally silty, slightly pyritic, hard and tight, ledge former. This is informally called the "lower green sandstone" of the Tuscarora/Rose Hill contact zone.	4.0

Unit		*Thickness (feet)*
	The upper and lower "green sandstones" of the Tuscarora/Rose Hill contact zone which occur here may be correlative with the Castanea sandstone (Swartz, 1934, p. 109).	
32	Interbedded shale (70 percent) and sandstone. Shale is medium dark gray (N4), in part silty to sandy, poorly fissile. Sandstone is light gray to very light gray, fine and medium grained, locally coarse grained, siliceous, very hard and tight, thin and medium bedded, crossbedded.	3.0
31	Shale, as above, fills scour eroded into underlying sandstone.	4.0
Tuscarora Formation (270 feet (82 m)—incomplete) (*See Figures 6 and 7*)		
30	Interbedded siliceous sandstone (60 percent) and silty shale. Sandstone is light gray to very light gray, fine and medium grained, locally coarse grained, siliceous, very hard and tight, medium and thin bedded, has trough-type crossbedding dipping northwest. Shale is medium gray (N4), silty, fairly fissile, very thin and thin bedded (2 mm to 2 inches thick). Shale locally becomes very finely sandy, having irregular thin beds and lenses of very fine grained pyritic sandstone. Top 5 feet of unit contains sandstone-filled burrow casts extending downward from sandstone beds into underlying shale.	24.0
29	Interbedded sandstone (80 percent) and shale. Sandstone is olive gray and greenish gray, becoming locally medium gray, pinkish gray, and buff toward top, weathers pinkish gray, very light gray, or buff, locally stained dark rusty brown; very fine to coarse grained, silty, poorly sorted, silica cemented, texture generally obscured by cement, locally argillaceous; medium bedded, with trough-type crossbedding generally dipping north to northwest (corrected). Interbedded shale is medium gray, silty, and light olive gray, sandy, thin bedded. Prominent trough cut into 2-foot sandstone bed 3 feet below top, dipping northward, filled with greenish-gray, thin-bedded, very finely silty shale.	19.0
28	Interbedded sandstone (70 percent) and shale. Sandstone is light olive gray to greenish gray, fine and very fine grained, with a few scattered coarse, subrounded, frosted quartz grains; silica cemented, very hard and tight, medium bedded, crossbedded, ripple marked. Shale is greenish gray to dark greenish gray, sandy to silty, poorly fissile, medium bedded, planar bedded; locally grades to siltstone, greenish-gray, argillaceous, very thin bedded, flat-bedded, locally very finely sandy.	19.0
27	Covered, with greenish-gray shale float at top.	3.0
26	Quartzite, medium-gray (N5 to N6), texture obscured by silica cement, medium- to thick-bedded, with trough-type crossbedding. Unit has 6-inch interbedded olive-gray, silty to sandy, fairly fissile shale unit near middle.	8.0
	Section offsets 100 feet southeast on top of unit 26. Lateral tracing of beds reveals consistent inclination of crossbedding, which dips northwest at an angle of approximately 15° to the bedding.	

Unit		*Thickness (feet)*
25	Covered.	7.0
24	Sandstone, medium-light-gray (N6), fine- and very fine grained, quartzitic, medium-bedded, flat-bedded to slightly crossbedded.	2.0
23	Shale, olive-gray to dark-greenish-gray, silty, fair to poor fissility, generally thin bedded.	2.0
22	Sandstone, medium-light-gray (N6), weathers rusty brown, fine grained, locally very fine grained, quartzitic, very hard and tight, medium-bedded, with low-angle crossbedding.	3.0

Units 22-32 in the Tuscarora Formation were measured from a temporary bench during the construction of the northbound lane of U.S. Route 22-322 in September 1967. The strata measured are several feet above the present road level. Units 12-21 in the Tuscarora Formation were measured in the bed of a small intermittent stream opposite utility pole #94864.

Unit		*Thickness (feet)*
21	Quartzite, light-olive-gray (5Y6/1), weathers pinkish gray to rusty orange (5YR8/1 to 10YR5/6), fine-, medium-, and coarse-grained, poorly sorted, medium-bedded, with trough-type crossbedding. Occasional light-olive-gray, < 1-cm-thick, < 1-foot-wide, flattened shale pebbles. Unit 21 is 20 percent covered.	7.0
20	Interbedded quartzite (90 percent) and shale. Quartzite is light olive gray (5Y6/1), weathers yellow gray and gray brown (5Y8/1 and 10YR3/2); fine and medium grained, with occasional coarse sand laminae; medium bedded (2 to 6 inches thick), irregularly bedded, possibly crossbedded. Possible gastropod trails 6 inches above base. Shale is moderate brown (5YR4/4), weathers grayish orange (10YR7/4), is silty to very finely sandy, hard, poorly fissile. Seen as float on covered intervals. Unit 20 is 15 percent covered.	10.0
19	Interbedded quartzite (95 percent) and shale. Quartzite is light olive gray (5Y5/2), weathers grayish orange (10YR7/4), with rusty-orange limonitic coating on fractures; predominantly fine and medium grained, poorly sorted, medium to thick bedded (½ to 3 feet thick), with trough-type crossbedding. Shale is light olive gray (5Y6/1), weathers yellow gray (5Y8/1), finely silty, very thin bedded, occurs as discontinuous lenses.	11.5
18	Shale, light-olive-gray (5Y6/1), weathers rusty orange (10YR5/6), very finely silty, micaceous, thin-bedded, fairly fissile. Quartzite (single 2-inch bed near middle of unit), medium-olive-gray (5Y5/1), weathers brown orange (10YR6/4), fine- to medium-grained, occupies a trough 2 to 4 inches thick.	1.5
17	Interbedded quartzite (95 percent) and shale. Quartzite is medium olive gray (5Y5/1), weathers dark yellow brown to rusty orange (10YR4/2 to 10YR5/5), is predominantly fine grained, locally fine to coarse grained, poorly sorted, with occasional shale clasts < 1 cm in diameter. Unit is medium bedded (1 to 2 feet thick), with trough-type crossbedding. Shale is light olive gray (5Y6/1), weathers yellow gray (5Y8/1), is thin bedded, planar bedded, occurs as two 3-inch beds 1½ feet and 5½ feet above base.	7.0

See Figure 4 for an illustration of units 17, 18, and 19.

Unit		*Thickness (feet)*
16	Interbedded shale (80 percent) and quartzite. Shale is medium olive gray (5Y5/1), weathers rusty orange (10YR5/6), is silty, slightly micaceous, locally sandy, with sandstone burrow casts. Unit is fairly fissile to splintery, locally hard and siliceous, thin bedded, with local planar crossbeds. Quartzite is olive gray (5Y3/2 to 5Y6/2), weathers rusty orange, is fine to coarse grained, poorly sorted, with occasional gray shale fragments. Thin bedded, irregularly flat bedded.	4.0
15	Interbedded quartzite (50 percent) and shale. Quartzite is light olive gray (5Y6/1), weathers yellow gray (5Y8/1), is fine to coarse grained, predominantly medium grained, poorly sorted, with occasional flattened shale pebbles (medium gray, silty, < ½ inch thick, < 2 inches wide). Unit is medium bedded, with trough-type crossbedding, and a few poorly developed load casts 2½ feet above base. Shale is thin bedded, silty, locally slightly sandy, micaceous, thin bedded, poorly fissile, blocky, with occasional asymmetrical ripple marks.	4.0
14	Quartzite, olive-gray to yellow-gray (5Y6/1 to 5Y8/1), weathers light yellow gray (5Y9/1) and locally rusty orange (10YR5/6); predominantly fine and medium grained, locally coarse grained, medium to thick bedded (½ to 3 inches thick), with trough-type crossbedding and occasional zones of flattened shale clasts (< 2mm thick, < 2 inches in diameter, medium gray, micaceous, silty), in a matrix of coarse-grained quartzite. Similar shale also occurs as discontinuous thin beds in upper foot.	4.0
13	Predominantly shale (70 percent) and quartzite. Shale is medium olive gray (5Y4/2), weathers very pale orange (10YR8/2), is silty, slightly micaceous, thin and very thin bedded, has fair to poor fissility. Quartzite is medium gray (N5 - N6), weathers yellow gray to rusty orange (5Y8/1 to 10YR5/6), is fine to coarse grained, predominantly fine and medium grained, thin to medium bedded (2 to 4 inches thick), generally flat bedded with few low-angle crossbeds. Unit includes a trace of medium-dark-gray, siliceous, argillaceous siltstone, transitional lithology between the shale and quartzite described above.	4.0
12	Interbedded quartzite (90 percent) and siltstone. Quartzite is olive gray to yellow gray (5Y4/2 to 5Y7/2), locally rusty orange, predominantly fine and medium grained, locally very fine to very coarse grained, poorly sorted, slightly limonitic, medium bedded, with trough-type crossbedding and a trace of vuggy porosity. Shale pebbles, medium-dark-gray and silty, occur in coarse- to very coarse grained quartzite 3 to 5 feet above base. Siltstone is olive gray (5Y3/2 to 5Y5/2), siliceous, slightly limonitic, locally argillaceous, thin bedded, flat bedded, hard and tight. Trace of light-olive-gray, silty shale in thin and very thin discontinuous beds.	12.5

Units 1-11 were measured at 11 different stations between utility pole #94884 and the axial plane of Tuscarora Mountain anticline, along the northeast side of U.S. Route 22-322.

11	Interbedded quartzite (80 percent) and shale. Quartzite is predominantly medium gray (N5 - N7), in part olive gray to yellow gray	

Unit		*Thickness (feet)*
	(5Y4/1, 5Y5/1, 5Y7/2), fine and medium grained, locally bimodal with scattered coarse quartz grains in fine-grained matrix, poorly sorted, locally slightly limonitic, with a trace of vuggy porosity. Coarser grains are subrounded and equant; texture of finer material is obscured by silica cement. Unit is medium bedded with trough-type crossbedding. Zone of scattered clay pebbles 2 feet above base. Prominent trough-shaped quartzite bed exposed southeast of culvert thickens from 1½ to 4 feet in a lateral distance of 10 feet, shown in Figure 5. Shale is medium gray to light olive gray (N5 to 5Y5/2), slightly micaceous, very silty, grading to argillaceous siltstone, locally very finely sandy, poorly fissile, blocky, thin and very thin bedded, flat bedded. *See Figure 5.*	11.0
10	Interbedded quartzite (60 percent) and shale. Quartzite is predominantly light gray (N5 to N7), locally yellow gray (5Y7/2) due to a trace of limonite, predominantly fine grained, locally fine to coarse grained, with occasional disc-shaped pebbles of gray silty shale, similar to the underlying shale strata. Quartzite is medium bedded, with flat bedding alternating with low-angle planar crossbeds. Trace of porosity, with few limonite-stained vugs. Shale is medium dark gray and olive gray (N4 and 5Y4/1), very slightly silty, noncalcareous, slightly micaceous, slightly limonitic in siltier beds, fair to poorly fissile, with occasional laminae of fine to medium sand.	11.0
9	Interbedded quartzite (90 percent), shale (10 percent), and siltstone (trace). Quartzite is yellow gray to light olive gray (5Y5/2 to 5Y7/2), locally light gray (N6 to N7), predominantly fine to medium grained, locally medium to very coarse grained, poorly sorted, medium bedded, in part crossbedded with planar and low-angle simple crossbeds. Occasional burrow casts of *Arthrophycus alleghenensis* filled with medium-grained olive-gray sand. Shale is pale olive gray and medium gray (5Y4/2 and N5), silty, slightly micaceous, noncalcareous with occasional sand laminae, fairly to poorly fissile, laterally grading to argillaceous siltstone, thin- to very thin bedded, flat bedded. Siltstone is medium gray, argillaceous, siliceous, slightly sandy, hard, locally slightly porous.	10.5
8	Interbedded shale (50 percent) and quartzite. Shale is medium gray and olive gray (N4 to N6 and 5Y5/1 to 5Y5/2), very silty, slightly siliceous, noncalcareous, poorly to fairly fissile, with occasional laminae of fine sandstone 5 mm thick. Quartzite is predominantly olive gray and yellow gray (5Y5/1 to 5Y6/1 and 5Y7/2), with occasional rusty limonitic spots; predominantly fine to coarse grained, locally very fine to coarse grained, poorly sorted, medium bedded, planar and trough-type crossbeds. Gray shale chips and pebbles ¼ to 2 inches in diameter occur rarely. *Arthrophycus alleghenensis* in float.	19.5
7	Shale (lower 3 inches) and quartzite. Shale is predominantly medium gray (N5 to N6), locally light olive gray (5Y6/1), very silty, slightly siliceous, poorly fissile, thin bedded, planar bedded, with occasional thin sand laminae. Shale beds grade laterally into siltstone. Quartzite is light gray and yellow gray (N6 to N8, 5Y7/2), very fine to medium grained, poorly sorted, pure, medium bedded, crossbedded.	7.5

Unit		*Thickness (feet)*
6	Interbedded quartzite and shale. Quartzite is medium light gray (N5 to N7), weathers light olive gray (5Y5/2), with rusty limonite staining on fractures, fine to coarse grained, mineralogically pure (> 98 percent quartz), has poor sorting with respect to size. Hard, tight, medium to thin bedded (½ to 3 feet); has trough-type crossbedding. Shale is less than 10 percent of unit, occurs in basal foot and in 4-inch bed in upper foot, is medium gray, locally light olive gray (N4 to N5 and 5Y6/1), very silty, locally very finely sandy, poorly fissile.	10.5
5	Quartzite, light-olive-gray (5Y5/2), weathers yellow gray (5Y7/2); predominantly medium and coarse grained, with occasional beds of fine sand and lenses of very coarse sand < 3 inches thick (4½ feet above base), very hard and tight, with occasional shale pebbles (< 1 inch in diameter, < ¼ inch thick, subrounded, medium dark gray, silty). Interbedded shale (< 5 percent of unit), light-olive-gray (5Y5/2), silty, poorly fissile, splintery, micaceous.	12.5
4	Quartzite, light-olive-gray to yellow-gray (5Y5/2 to 5Y7/2), predominantly medium and coarse grained; coarse sand is well rounded, finer sand texture largely obscured by silica cement. Fair to poor sorting, very hard and tight, locally limonitic in weathered zone. Irregularly medium bedded, in part crossbedded. Minor amount of interbedded shale, light-olive-gray (5Y5/2), very silty, locally very finely sandy, micaceous, poorly fissile.	5.5
3	Interbedded quartzite (80 percent) and shale. Quartzite is yellow gray to light olive gray (5Y7/2 to 5Y5/2), fine to coarse grained, poorly sorted, with scattered limonite spots < 3 mm in diameter and flattened shale pebbles in lower 4 feet (< 1 inch in diameter, < 1 inch thick, well rounded), similar to underlying shale. Medium bedded, with planar crossbedding and occasional very thin discontinuous siltstone laminae. Shale is light olive gray to pale olive gray, and locally very finely sandy, slightly micaceous, poorly fissile.	10.0
2	Interbedded quartzite (80 percent) and shale. Quartzite is yellowish gray to light olive gray (5Y7/2 to 5Y5/2), weathers rusty orange, fine and medium grained, locally coarse grained, irregularly medium bedded, faintly crossbedded, very hard and tight, with occasional burrows. Shale is olive gray to light olive gray (5Y3/2 to 5Y5/2), very silty, slightly micaceous, fairly fissile, medium to very thin bedded (< 4 inches thick).	10.5
1	Interbedded quartzite (60 percent) and shale. Quartzite is light olive gray (5Y5/2), weathers dark yellow orange to rusty light brown (10YR6/6 to 5YR4/4); fine to coarse grained, predominantly medium grained, slightly limonitic on weathered surface, medium bedded, crossbedded with planar and trough-type crossbeds; very hard and tight. Shale is predominantly light olive gray to yellow brown, locally medium gray (5Y5/2 to 5Y5/4, N5), very silty, grading laterally to siltstone.	9.0

LOCALITY 2. LOST CREEK RIDGE

The most productive mineral extraction activity in the Millerstown quadrangle at the present time is the Juniata Limestone Company quarry on Lost Creek Ridge. This quarry is located in Fayette Township, Juniata County, in the northwest corner of the Millerstown 7½-minute quadrangle (Figure 101). The rocks quarried here include the upper 15 feet (4.6 m) of the Silurian Tonoloway Formation and the lower 46 feet (14 m) of the overlying Silurian and Devonian Keyser Formation. An additional 17 feet (5.2 m) of the Keyser Formation which is unsuitable for commercial use is stripped from above along with a thin overburden of soil. Although neither the Keyser nor the Tonoloway Forma-

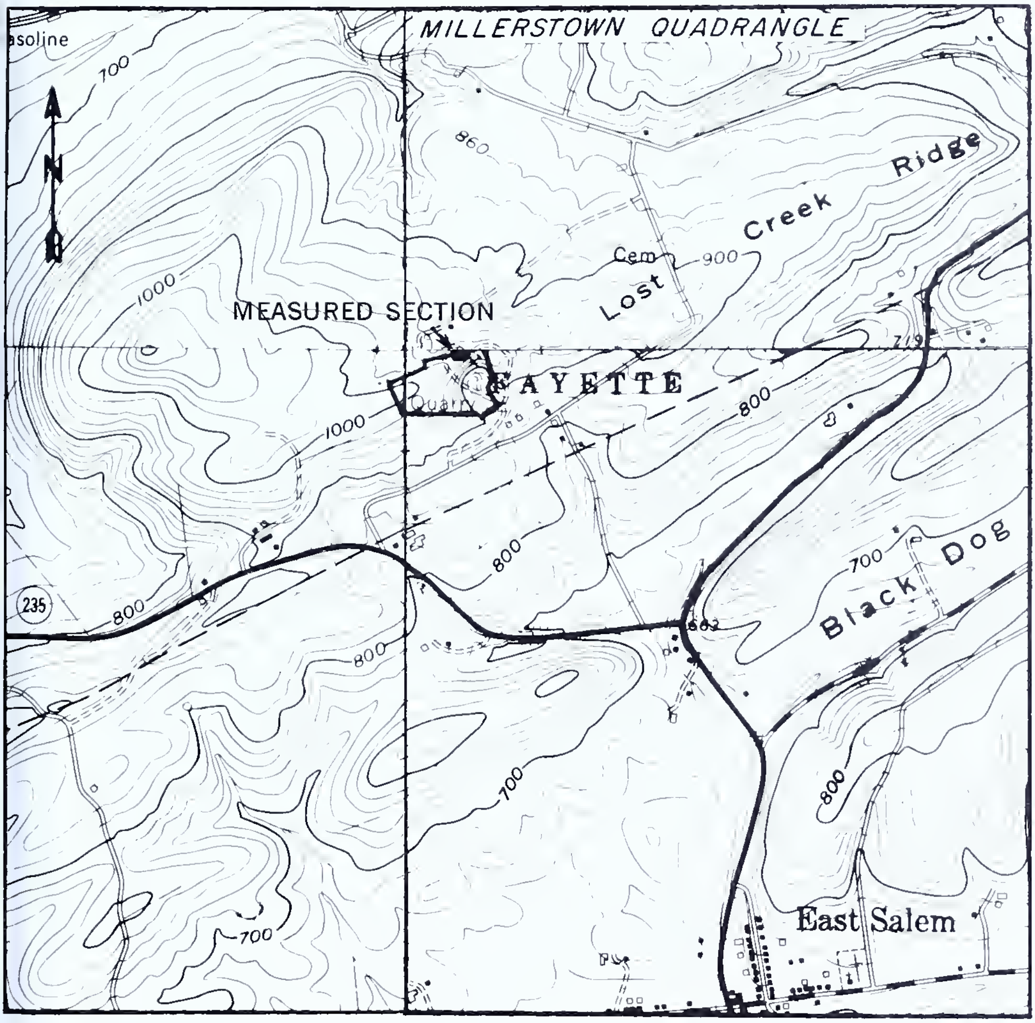

Figure 101. Location of measured section in Keyser and Tonoloway Formations on Lost Creek Ridge.

tion is completely exposed here, the section is included in this report because of the excellent exposure and its economic importance (Figures 18 and 19).

This section was measured on the north wall of the quarry, at a point some 600 feet (183 m) east of 77°15′ west longitude and 200 feet (61 m) south of 40°37′30″ north latitude. Access to the section was possible along a ramp recently cut through the north wall.

The strata here are very nearly horizontal, situated on the crest of the flat-topped Lost Creek anticline. The 78-foot (24-m) interval measured is 100 percent exposed. This interval includes approximately half of the total thickness of the Keyser Formation, and perhaps three percent of the underlying Tonoloway Formation. The section was measured and units numbered from the base to the top, and is described below in the descending order.

Keyser Formation (63 feet (19 m)—incomplete)

Unit		*Thickness (feet)*
7	Limestone, medium-dark-gray (N4), weathers yellow gray (5Y6/2), microcrystalline, argillaceous, slightly silty, fossiliferous. Irregularly bedded, medium bedded in lower half, thin bedded above. Very nodular, "lumpy," fairly hard and tight. Skeletal material includes disarticulated fragments of brachiopod and pelecypod shells, crinoid columnals, and ostracods.	17.0
6	Limestone, medium-gray (N5), skeletal micritic calcarenite, locally argillaceous, thick-bedded. Becomes very cobbly to nodular where weathered. Fossil material is mainly broken shell fragments. *Forms prominent ledge at top of quarry wall.*	3.0
5	Limestone, medium-gray (N5), microcrystalline, slightly argillaceous, hard and tight. Medium and thick bedded on fresh exposure; weathers to medium and thin, very irregular cobbly beds 1 to 6 inches thick.	5.0
4	Limestone, medium-gray (N5), microcrystalline, hard and tight. Irregular medium bedding.	8.0
3	Limestone, medium-gray to medium-dark-gray (N4 to N5), microcrystalline, fossiliferous, thick-bedded (2 to 4 feet thick), irregularly flat bedded. Fossil material not identifiable on fresh exposures.	13.0
2	Limestone, medium dark gray (N4), microcrystalline to very finely crystalline, hard and tight. Thin and medium bedded (1 to 4 inches thick), irregular bedding. Occasional fluorite veins, coarse crystalline aggregates, gray-purple (5P4/2) to colorless.	2.0
1	Limestone, dark-gray (N3 to N4), microcrystalline, locally slightly argillaceous, with occasional white calcite veins; slightly fossiliferous, medium and thick bedded (1 to 4 feet thick), planar bedded, tight.	15.0

Tonoloway Formation (15 feet (5 m)—incomplete)

3	Limestone, dark-gray (N3), microcrystalline, slightly fossiliferous, thin-laminated, tight. Fauna includes scattered brachiopod and	

	pelecypod shells. Unit includes a one-inch-thick, medium-olive-gray (5Y5/1), calcareous, fossiliferous, very fissile, soft, papery shale bed at the top.	4.5
2	Limestone, medium-gray (N5), weathers yellowish gray (5Y7/2) to pale yellow brown (10YR6/2); microcrystalline, slightly argillaceous, very thin bedded, flat-bedded, slightly fissile. This unit is a conspicuous bed which can be traced around the entire perimeter of the quarry.	1.0
1	Limestone, medium-dark-gray (N4), microcrystalline, part thinly laminated, part massive, hard and tight. Locally stylolitic, with few possible algal-mat structures.	9.5

LOCALITY 3. WARDVILLE DEVONIAN SECTION

This stratigraphic section was measured in Lower and Middle Devonian rocks in the valley between Lock and Turkey Ridges, along Cocolamus Creek 0.3 mile (0.5 km) north of a road junction known as Wardville (Figure 102). The section lies in Greenwood Township, Perry County, in the Millerstown 7½-minute quadrangle, and was measured by D. M. Hoskins and J. P. Wilshusen in 1964 and slightly modified by the authors. The measured section, in north-dipping beds, includes the Needmore, Selinsgrove, and Tioga Members of the Onondaga Formation

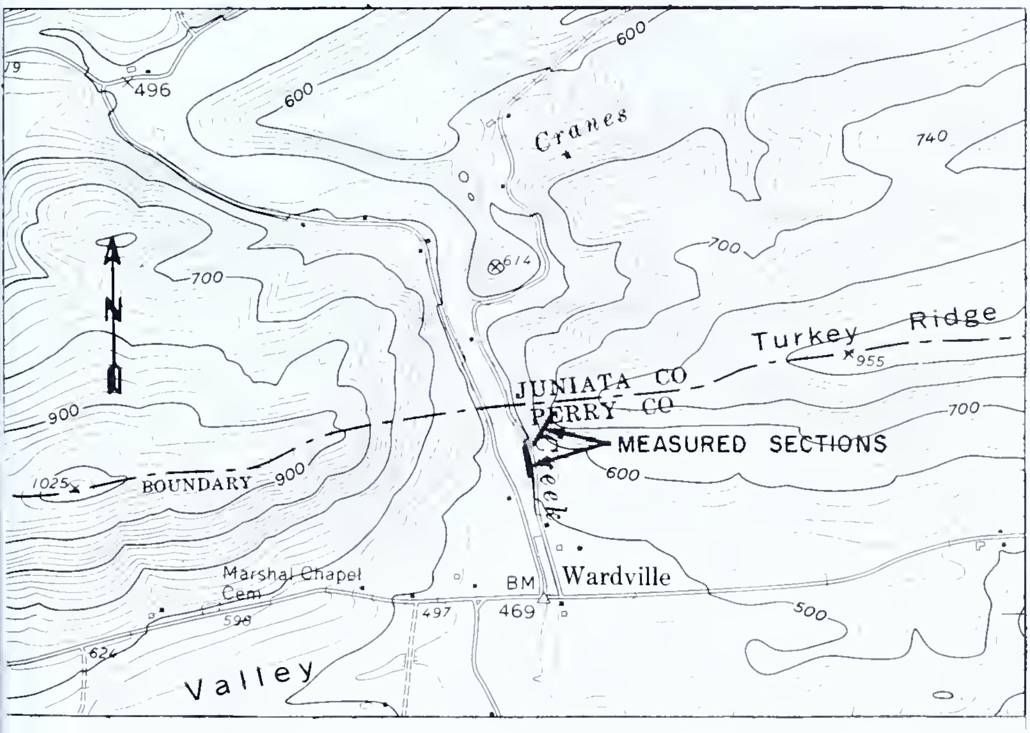

Figure 102. Location map, Wardville Devonian section.

Table 35. *Summary of Measurements: Wardville Devonian Section*

Units	Formation	Thickness (feet)	Thickness (meters)	Covered intervals (feet)	Covered intervals (meters)	Amount exposed
25–35	Mahantango Formation					
32–35	Dalmatia Member (partial)	180.0	54.8	133.8	40.8	26%
25–31	Turkey Ridge Member	79.0	24.1	24.8	7.6	69%
	Total Mahantango Formation	259.0	78.9	158.6	48.4	39%
23–24	Marcellus Formation	106.0	32.3	31.0	9.5	71%
1–22	Onondaga Formation					
20–22	Tioga bentonite beds	4.5	1.4	0.3	0.1	93%
3–19	Selinsgrove Member	94.2	28.7	22.8	7.0	77%
1–2	Needmore Member	68.0	20.7	none	none	100%
	Total Onondaga Formation	166.7	50.8	23.1	7.1	86%
Total section:		531.7	162.0	212.7	65.0	60%

(Figure 24), the Marcellus Formation (Figure 25), the Turkey Ridge Member, and a part of the Dalmatia Member of the Mahantango Formation. The attitude of the beds is quite consistent across the measured section, with the strike averaging N79E and the dip 44 degrees to the north. Thickness of stratigraphic units and proportion of covered intervals are given in Table 35.

The base of the section is located on the east bank of the stream, 4,900 feet (1,494 m) west of 77°07′30″ west longitude, and 1,350 feet (411 m) north of 40°35′ north latitude. The top of the section is at the top of Turkey Ridge, 4,600 feet (1,402 m) west of 77°07′30″ west longitude and 2,000 feet (610 m) north of 40°35′ north latitude.

The units in each formation are numbered from bottom to top; the section is described below, beginning with the highest unit.

Mahantango Formation (259 feet (79 m)—incomplete)
Dalmatia Member (180 feet (55 m)—incomplete)

Unit		*Thickness (feet)*
35	Sandstone, light-olive-gray (5Y6/1), mostly fine grained, poorly sorted, few medium grains, medium-bedded (1 to 6 inches). Lower part of unit is very fine grained, crossbedded. *Unit is on overgrown logging road at crest of hill.*	20.0
34	Sandstone, medium-light-gray (N6), fine-grained, medium-bedded, scattered exposures in covered interval. Eighty-five percent covered.	75.0
33	Sandstone, light-olive-gray (5Y6/1), very fine to fine-grained, thin- to medium-bedded (1/8 to 2 inches). Some 2-inch beds are fissile. The lower 3 feet is crossbedded and massive, but becomes platy laterally. Twenty-five percent covered.	20.0
32	Covered. Slope wash is sandstone similar to overlying units.	65.0
Turkey Ridge Member (79 feet (24 m)—complete)		
31	Sandstone, light-olive-gray (5Y6/1), fine-grained, medium-bedded (2 inches), platy weathering, 30 percent covered at base.	4.5
30	Sandstone, greenish-gray (5GY6/1), fine-grained, few medium grains, poorly sorted, medium- to thick-bedded (2 to 18 inches), generally massive, crudely crossbedded.	8.0
29	Sandstone, light-olive-gray (5Y6/1), fine- to medium-grained, poorly sorted, medium- to thick-bedded (3 to 24 inches), crossbedded near top. Fifty percent covered.	6.0
28	Sandstone, light-olive-gray (5Y6/1), very fine to medium-grained (upper half very fine to fine grained), poorly sorted in lower half, medium-bedded (2 to 8 inches), crudely crossbedded. Upper half is cliff former. Lower half partially covered. Spheroidal weathering pits 2 feet by 3 feet in upper beds.	18.5
27	Sandstone, light-olive-gray (5Y6/1), fine- to medium-grained, poorly sorted, medium-bedded (1 inch to 12 inches), crudely crossbedded with disrupted bedding near center of unit; massive cliff former.	15.5
26	Covered.	14.0

Unit		*Thickness (feet)*
25	Sandstone, light-olive-gray (5Y6/1) grading down to medium dark gray (N4), very fine to fine-grained, medium-bedded (1 inch to 4 inches), crudely crossbedded. Exfoliation on bedding planes throughout member. Twenty percent covered.	12.5
Marcellus Formation (106 feet (32 m)—complete)		
24	Covered.	31.0
23	Shale, grayish-black (N2), well-developed joint surfaces weather dark yellowish orange (10YR6/6); fissile. Limestone nodules occur 52 feet below top. Weathered clay nodules (siderite concretions) with limestone in the center occur 26 feet and 40 feet above Tioga K-bentonite. Twenty-five feet above the bentonite, a 4-inch calcareous claystone occurs. Claystone is dark gray (N3) and weathers to a dusky-brown (5YR2/2) clay. Limestone nodules occur 14 inches above claystone (*see Figure 25*).	75.0
Onondaga Formation (166.7 feet (50.8 m)—complete)		
Tioga beds (4.5 feet (1.4 m)—complete)		
22	Metabentonite. Clay, 1 inch, medium-dark-gray (N4) to brownish-gray (5YR4/1). Clay, 2 inches, dark-yellowish-brown (10YR4/2), weathers dark yellowish orange (10YR6/6); sandstone, 4 inches, weathered, micaceous, medium-gray (N5), flecked with fine-grained, well-sorted, very light gray (N8) sandstone. Siltstone, 1 inch, very fine grained, grayish black (N2). Shale, 2 inches, clayey, grayish-black (N2). Clay, 5 inches, olive-black (5Y2/1).	1.2
21	Limestone, 1.25 feet, dense, dark-gray (N3). Covered, 0.3 foot, probably shale. Limestone, 1.25 feet, dense, medium-dark-gray (N4).	2.3
20	Metabentonite(?). Shale, 0.5 foot, fissile, grayish-black (N2), calcite(?) in weathered fractures. Sandstone, 0.1 foot, very fine grained, micaceous, olive-gray (5Y4/1). Sandstone, 0.2 foot, clayey, micaceous, weathered. Sandstone, 0.1 foot, very fine grained, micaceous, olive-gray (5Y4/1). Shale, 0.1 foot, clayey, grayish-black (N2), calcite(?) in weathered fractures.	1.0
Selinsgrove Member (94.2 feet (29 m)—complete)		
19	Limestone, dark-gray (N3), finely crystalline, argillaceous, siliceous pellets weather out giving surface a rough texture. Grades into unit 18.	0.3
18	Limestone, medium-dark-gray (N4), very finely crystalline, dense, lower 0.1 foot shaly.	0.4
17	Limestone, dark-gray (N3), finely crystalline; single bed with comminuted fossil debris on surface (*see Figure 24*).	1.0
16	Shale, grayish-black (N2), calcite(?) in weathered fractures.	0.3
15	Limestone, medium-dark-gray (N4), finely crystalline, medium-bedded (4 to 5 inches), intercalated with calcareous, medium-dark-gray (N4) shale. Upper surface of unit is reniform.	1.3
14	Limestone, medium-dark-gray (N4), finely crystalline; lower 0.2 foot becomes shaly and dark gray (N3). Upper surface reniform.	2.0
13	Limestone, finely crystalline, 3-inch platy calcite bed at base.	0.8
12	Limestone, medium-dark-gray (N4). Upper 1 inch is shaly, dark-gray (N3) limestone showing distinct cleavage.	0.8

Unit		*Thickness (feet)*
11	Limestone, medium-dark-gray (N4). Upper 1 inch is shaly and shows distinct cleavage.	1.8
10	Limestone, medium-gray (N5), finely crystalline, thin- to medium-bedded ($<$ 1 inch to 2 inches), lumpy texture with disrupted bedding in center of unit.	5.0
9	Covered.	3.0
8	Limestone, medium-dark-gray (N4), alternating with shale, 8- to 10-inch beds, calcareous. Seventy-five percent covered.	15.0
7	Limestone, medium-dark-gray (N4), medium- to thick-bedded (6 to 12 inches), fractured normal to bedding. Some beds separated by 2- to 4-inch calcareous shales which increase in amount in upper part of unit. Upper shales are 6 inches thick and upper limestones 2 to 4 inches. Twenty percent covered.	14.0
6	Limestone, dark-gray (N3), very finely crystalline, platy weathering, contains several 1-foot interbeds of medium-gray (N5) finely crystalline limestone. Upper beds shaly.	10.0
5	Covered.	5.5
4	Limestone, medium-gray (N5), thin- to medium-bedded, blocky weathering. Lower 2 feet shaly. Prominent 4-inch zone of 3-inch limestone nodules 2.5 feet above base.	9.0
3	Limestone, medium-dark-gray (N4), very finely crystalline, medium-bedded (6 to 8 inches), alternating with dark-gray (N3), calcareous, silty shale. Shale beds are 1 foot thick near top, 4 feet thick near base. Lower limestone beds are platy and argillaceous.	24.0
	Needmore Member (68.0 feet (21 m)—incomplete)	
2	Shale, medium-gray (N5) to medium-light-gray (N6), fissile, calcareous. Few shaly limestone beds in gradational contact with shale. Limestone $>$ 5 percent. Fossils in 3-inch-thick limestone lens 1 foot above base. Scattered fossils in shale.	23.0
1	Shale, medium-gray (N5) to light-olive-gray (5Y6/1), olive-gray (5Y4/1) near base, fissile, noncalcareous.	45.0

LOCALITY 4. DONNALLY MILLS

The only Turkey Ridge Member exposure in this area in which both the top and base can be seen is along county road 50005 where it follows Buckwheat Run through Raccoon Ridge south of Donnally Mills, Pennsylvania. This village is located 5 miles west of Millerstown in Perry County, in the Millerstown 7½-minute quadrangle.

The section extends from a point 0.3 mile south of the junction of this road with Pa. Route 17 southward along the west side of the road to a prominent sandstone outcrop south of the south end of a small abandoned quarry. This quarry is located approximately 4,200 feet (1,280 m) east of 77°15′ west longitude and 4,500 feet (1,372 m) north of 40°30′ north latitude (Figure 103). The section is 328 feet (100 m) thick, and is 75 percent exposed. The average strike of the rocks here is N64E, and

Table 36. *Summary of Measurements: Donnally Mills Section*

Units	Formation	Thickness (feet)	Thickness (meters)	Covered intervals (feet)	Covered intervals (meters)	Amount exposed
4–11	Mahantango Formation					
11	Montebello Member (partial)	6.0	2.0	none	none	100%
10–9	Fisher Ridge Member	191.0	58.2	66.0	20.1	65%
8–4	Turkey Ridge Member	124.0	37.8	60.0	18.3	52%
	Total Mahantango Formation	321.0	98.0	126.0	38.4	61%
3–1	Marcellus Formation (partial)	79.0	24.1	22.0	6.7	72%
Total section:		400.0	122.1	148.0	45.1	63%

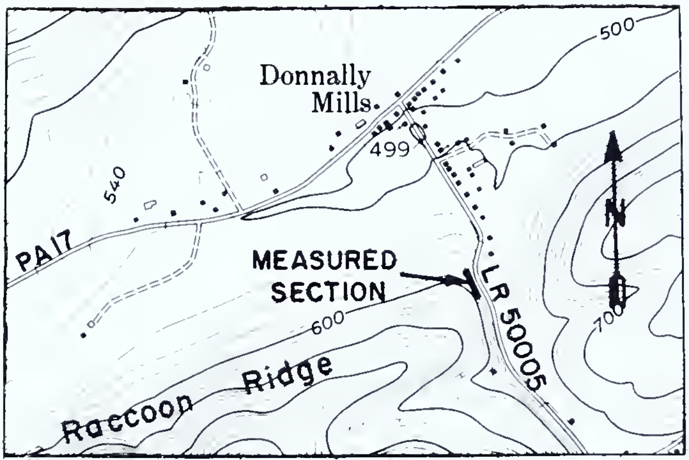

Figure 103. Location map, Donnally Mills Devonian section.

the dip is to the south at 56 degrees. The line of exposure is approximately normal to the strike direction.

The lower 125 feet of the Fisher Ridge Member of the Mahantango Formation can be seen here, which is the most complete exposure of this member available in this quadrangle at the present time (see Figure 28). Thicknesses of stratigraphic units and proportion of covered intervals are summarized in Table 36.

The section was measured from the bottom to the top, and is described below, beginning with the highest unit.

Mahantango Formation (321.0 feet (98 m)—incomplete)

Montebello Member (6.0 feet (1.8 m)—incomplete)

Unit		*Thickness (feet)*
11	Sandstone, light-olive-gray, fine- to very fine grained, siliceous, thick-bedded, planar-bedded, locally coarse grained; grain size increases upwards within beds.	6.0
	Fisher Ridge Member (191 feet (58 m)—complete)	
10	Covered.	66.0
9	Interlaminated siltstone and shale exposed in quarry. Siltstone is medium olive gray (5Y5/1 to 5Y4/2), slightly siliceous, argillaceous, very finely sandy in lower half, locally calcareous in upper half. Laminations 1 mm to 1 cm thick, locally ripple marked. Shale is dark olive gray to olive black (5Y2/1 to 5Y3/1), slightly silty, highly fissile, possibly slightly carbonaceous, in laminations 1 mm thick; forms approximately 20 percent of unit. Color gradually changes to dark gray (N2 to N4) in upper half. Two prominent steeply dipping joint sets are present in this unit: J1 strikes N24W, dips 83W, J2 strikes N23W, dips 85E. *See Figure 28.*	125.0

Turkey Ridge Member (124.0 feet (38 m)—complete)

Unit		*Thickness (feet)*
8	Sandstone, medium-olive-gray (5Y5/1 to 5Y4/2), fine- and very fine grained, locally silty, slightly siliceous, fairly porous, medium-bedded, planar-bedded.	1.0
7	Covered.	60.0
6	Sandstone, medium- to light-olive-gray (5Y5/1 to 5Y6/1), very fine grained, locally very fine to medium grained, slightly siliceous, slightly limonitic, slightly porous. Irregularly medium bedded, upper half is partly covered.	25.0
5	Siltstone, light-brown to pale-yellowish-brown (5YR6/4 to 10YR6/2), weathers yellow orange (10YR7/6), argillaceous, locally very finely sandy, thin- and very thin bedded, with laminae of very fine sandstone and shale. The shale laminae are pale yellow brown (10YR6/2), silty, have dull to subwaxy luster, are fairly fissile, in regular laminations 1 mm thick. Unit is highly contorted, and is lithologically similar to the upper beds in the underlying Marcellus Formation.	8.0
4	Sandstone, light- to medium-olive-gray (5Y5/1 to 5Y6/1), very fine grained, silty, siliceous, hard and tight, medium-bedded, locally crossbedded, with occasional thin interbeds of light-olive-gray argillaceous siltstone.	30.0
Marcellus Formation (79.0 feet (24 m)—incomplete)		
3	Interlaminated shale and siltstone. Shale is medium dark gray (N4), weathers light olive gray (5Y6/1) to "buff"; is finely silty, slightly carbonaceous, fairly fissile; has dull luster. Siltstone is gray orange (10YR7/4), argillaceous, slightly limonitic. Unit includes laminae and interbeds up to 6 inches thick of sandstone, light-brown to dark-yellow-orange (5YR6/4 to 5YR6/6), very fine grained, silty, slightly siliceous and limonitic, fairly porous, thin-bedded, planar-bedded. Sandstone comprises less than 10 percent of unit. The bedding in the upper few feet of the unit is somewhat contorted, and reflects irregularities on the sole of the overlying sandstone.	21.0
2	Covered. Float resembles enclosing strata.	22.0
1	Shale, very dark gray to black (N1 to N2), locally brownish black (5YR2/1), pure to very finely silty, carbonaceous, moderately hard and fissile.	36.0

LOCALITY 5. SHADLE

The Shadle section includes most of the Montebello and Sherman Ridge Members (including the "Shadle sandstone") of the Middle Devonian Mahantango Formation. The section was measured along the east side of Pa. Route 104 at the village of Shadle, Pennsylvania, in Perry Township, Snyder County. The base of the section is at the first road intersection north of Shadle, and the top is south of Shadle at the junction of Pa. Route 104 with county road 54010, as shown in Figure 104. This area is in the Dalmatia 7½-minute quadrangle approximately one-half mile from the east edge of the Millerstown 15-minute (Richfield

Table 37. *Summary of Measurements: Shadle Devonian Section*

Unit	Formation	Thickness (feet)	Thickness (meters)	Covered intervals (feet)	Covered intervals (meters)	Amount exposed
1–38	Mahantango Formation					
	Sherman Ridge Member**					
35–38	Upper cycle	273.0	83.2	193.5	59.0	29%
31–34	"Shadle sandstone"*	72.0	21.9	none	none	100%
26–30	Lower shaly beds*	178.0	54.2	10.0	3.0	94%
26–38	Total Sherman Ridge Member	523.0	159.3	203.5	62.0	61%
1–25	Montebello Member (partial)	269.0	82.0	36.5	11.1	86%
Total section:		792.0	241.3	240.0	73.1	70%

* The "Shadle sandstone" and the lower shaly beds together comprise the lower of two upward-coarsening cycles in the Sherman Ridge.

** There is an additional thickness of approximately 100 feet of Sherman Ridge Member in the covered interval above this section.

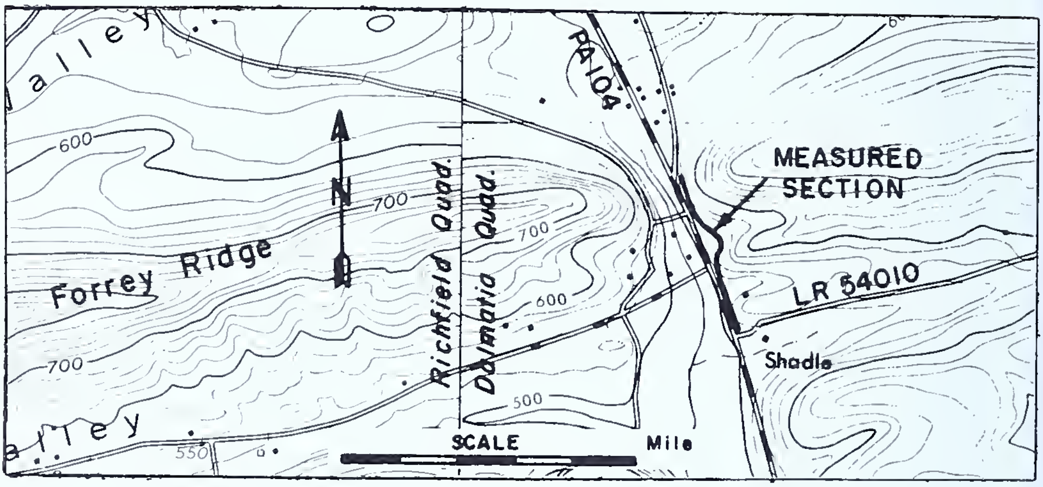

Figure 104. Location map, Shadle Devonian section.

7½-minute) quadrangle, in a small valley formed where the north branch of Mahantango Creek crosses Forrey Ridge (Figure 34). Thicknesses of stratigraphic units and proportions of covered intervals are given in Table 37.

The base of this section is located 1,800 feet (549 m) east of 77°00′ west longitude, and 500 feet (152 m) south of 40°42′30″ north latitude. The top of the section is approximately 2,400 feet (732 m) east and 1,850 feet (564 m) south of the same coordinates. There is 269 feet (82 m) of Montebello Formation present in this section, of which 232 feet (71 m), or 86 percent, is exposed. The lower 523 feet (160 m) of the Sherman Ridge Member is included in this section, of which 320 feet (98 m), or 61 percent, is exposed. This includes the 73-foot (22-m) -thick "Shadle sandstone," which is 100 percent exposed.

The "Shadle sandstone" is an informal name for the lower, upward-coarsening sandstone and siltstone cycle in the Sherman Ridge Member. The "Shadle sandstone" has a fairly local extent and is probably not traceable very far beyond the borders of the Millerstown and Millersburg 15-minute quadrangles. The strike of the rocks varies from N73E to N86E, and the dip ranges from 31S to 40S. The exposure trends approximately in the dip direction, which facilitates measurement of bed thicknesses. The top of the section is approximately 50 feet (15 m) below the top of the Sherman Ridge Member.

Mahantango Formation (792.0 feet (241 m)—partial)

Sherman Ridge Member (523.0 feet (159 m)—partial)

Upper shaly beds (273.0 feet (83 m)—partial)

Unit		*Thickness (feet)*
38	Claystone, mottled olive-gray and dark-gray (5Y3/1 to 5Y4/1), silty, fossiliferous, splintery, medium- to thin-bedded. Units include a few	

Unit		Thickness (feet)
	thin beds of sandstone, light-olive-gray (5Y6/1), very fine to fine-grained, planar-bedded, very thin bedded, with clay partings on bedding planes. Unit is highly burrowed, and fauna includes well preserved crinoids. Fifty percent covered. *Upper part is well exposed in a new excavation behind a house at the junction of county road 54010 with Pa. Route 104.*	87.0
37	Covered interval. Float is medium-gray splintery shale.	146.0
36	Shale and claystone, olive-gray (5Y4/1), weathers medium gray (N5), pure to very finely silty, splintery, locally fairly fissile.	36.0
35	Covered.	4.0
	"Shadle sandstone" beds (72.0 feet (22 m)—complete)	
34	Sandstone, medium-gray to medium-dark-gray (N4 to N5), weathers light olive gray (5Y6/1); very fine grained, locally fine grained to silty, becomes coarser toward top, slightly calcareous and siliceous, medium and thick bedded, planar bedded, hard and tight. *See Figure 34.*	30.0
33	Sandstone, medium-dark-gray (N4), very fine grained, silty, slightly argillaceous and calcareous, medium- to thick-bedded, planar-bedded, hard and tight. Poorly preserved symmetrical ripple marks trend N60E. *Top of unit is at base of Pa. Route 104 sign.*	24.0
32	Siltstone, medium-dark-gray (N4), argillaceous, locally becoming very finely sandy, with occasional 2-inch lenses of sandstone, rusty-brown, very fine grained, silty, hematitic, very hard, nodular.	6.0
31	Siltstone, medium-dark-gray (N4), argillaceous, medium-bedded, partly calcareous, locally grading to silty claystone.	12.0
	Lower shaly beds (178.0 feet (54 m)—complete)	
30	Shale, medium-dark-gray to olive-gray (N4 to 5Y4/1), silty, fossiliferous (fauna predominantly brachiopods), grades upward into silty claystone and argillaceous siltstone, with occasional laminae of very fine sandstone.	30.0
29	Covered interval behind building. *Dirt road leads into woods to the east.*	10.0
28	Claystone, olive-gray (5Y4/1), micaceous, fossiliferous, slightly silty, locally carbonaceous, cobbly to splintery, Locally poorly fissile depending on the degree of weathering; spheroidal weathering.	108.0
27	Shale, olive-gray (5Y4/1), slightly silty, fossiliferous, fair to poor fissility. Fauna includes brachiopods, fish vertebrae, and bone fragments, particularly in the lower 5 feet.	25.0
26	Sandstone, dark-yellow-gray to yellow-brown (5Y7/1 to 10YR5/2), mottled, very fine grained, silty, argillaceous, grades upward into sandy siltstone and claystone. Siltstone is dark yellow brown (10YR4/2), argillaceous, locally sandy, with scattered medium to coarse quartz sand grains which are well rounded and frosted. Fossiliferous, medium bedded, spheroidal weathering. Top is gradational with unit 27.	5.0
	Montebello Member (269.0 feet (82 m)—incomplete)	
25	Sandstone, light-olive-gray (5Y6/1), fine-grained, slightly siliceous, fossiliferous, single bed. Fauna predominantly *Spirifer* brachiopods. *See Figure 30.*	2.0

Unit		*Thickness (feet)*
24	Sandstone, mottled olive-gray, medium-dark-gray, and dark-yellow-brown (5Y4/2, N4, 10YR4/2), very fine grained, locally fine grained, siliceous, slightly calcareous, fossiliferous. Fauna predominantly *Spirifer* brachiopods in random orientation in burrowed sand.	7.0
23	Sandstone, medium-gray to medium-dark-gray (N4 to N5), very fine grained, siliceous, slightly calcareous on fresh exposure, medium- to thick-bedded, fossiliferous. Six-inch lens of skeletal debris occurs 5 feet below the top, consisting mainly of small brachiopods and crinoid columnals.	15.0
22	Sandstone, similar to underlying unit 21, but less well exposed. Unit is 30 percent covered.	25.0
21	Sandstone, medium-gray to medium-dark-gray (N4 to N5), weathers light olive gray (5Y6/1); very fine to fine-grained, siliceous, locally slightly calcareous, medium-bedded, planar-bedded. Appears to be well sorted and homogeneous, but texture is largely obscured by cement.	20.0
20	Sandstone, medium-dark-gray to light-olive-gray (N5 to 5Y6/1), very fine grained, siliceous, locally argillaceous, medium-bedded, planar-bedded, fossiliferous, with large brachiopod shells and clay-filled burrows.	24.0
19	Interbedded sandstone (50 percent) and shale. Sandstone is in alternating layers of medium gray and medium dark gray (N4, N5), very fine grained, locally grading to silt, siliceous, locally argillaceous and slightly micaceous, medium and thin bedded, planar bedded, ripple marked, hard and tight, locally burrowed. Shale is medium dark gray (N4), silty to very finely sandy, locally micaceous, poorly fissile. Unit contains a few well-preserved cephalopod shells.	17.0
18	Sandstone, olive-gray (5Y4/1), very fine to fine-grained, siliceous, locally argillaceous, with irregular clay-lined burrows. Medium bedded, planar bedded.	11.0
17	Covered.	3.0
16	Sandstone, medium-light-gray, very fine grained, siliceous, medium-bedded, planar-bedded, hard and tight.	5.0
15	Sandstone, olive-gray (5Y4/1), very fine grained, silty, micaceous, siliceous, locally argillaceous, with traces of hematite, becoming limonitic in weathered zone, medium-bedded, planar-bedded. Poorly developed ripple marks, burrows, and scattered crinoid columnals.	22.0
14	Interbedded sandstone (80 percent) and shale (20 percent). Sandstone is light olive gray (5Y6/1), very fine grained, slightly siliceous, argillaceous, locally micaceous, thin bedded, has interference ripple marks, rare crinoid columnals, and burrows parallel to bedding planes. Shale is olive gray, sandy to silty, in zones less than 2 inches thick.	15.0
13	Shale, olive-gray (5Y6/1), silty to sandy, with interbedded medium-light-gray (N5), very fine grained sandstone in irregular beds less than 1 cm thick.	2.0
12	Sandstone, medium-light-gray (N5), very fine grained, locally fine grained, siliceous, medium-bedded, flat-bedded, very hard and tight. Texture obscured by cement.	11.0

Unit		Thickness (feet)
11	Sandstone, light-olive-gray (5Y6/1), very fine grained, slightly siliceous and argillaceous, thin- and very thin bedded, planar-bedded, lower 2 feet covered.	3.0
10	Sandstone, light-gray (N7), weathers light olive gray (5Y6/1): very fine grained, siliceous, with occasional flattened dark-gray, silty clay pebbles less than 1 mm thick and 2 cm long.	5.0
9	Sandstone, light-olive-gray (5Y6/1), very fine to fine-grained, siliceous, locally limonitic in weathered zone, very thin and thin-bedded, ripple-marked, hard and tight.	5.0
8	Shale, light-olive-gray to dark-yellow-brown (5Y6/1 to 10YR4/2), silty. Interbedded sandstone, light-olive-gray, very fine grained, silty, in very thin beds.	25.0
7	Sandstone, light-olive-gray (5Y6/1), very fine grained, siliceous, thick-bedded to massive, limonitic in weathered zone, very hard and tight.	10.0
6	Covered.	13.0
5	Sandstone, medium light-gray to light-olive-gray (N6 to 5Y6/1), very fine grained, argillaceous, siliceous, thin- and very thin bedded, hard and tight. Unit includes discontinuous laminae and lenses of olive-gray (5Y4/1) shale.	3.0
4	Covered.	11.0
3	Sandstone, light-olive-gray (5Y6/1), very fine grained, siliceous, medium-bedded, hard and tight.	5.0
2	Interbedded shale (80 percent) and sandstone (20 percent). Shale is light olive brown to moderate yellow brown (5Y5/6 to 10YR5/4), generally silty, locally sandy. Sandstone is light olive gray (5Y6/1), argillaceous, thin bedded, with occasional carbonaceous clay pebbles.	4.0
1	Sandstone, light-olive-gray (5Y6/1), very fine grained, slightly siliceous, well-sorted, medium-bedded, hard and tight, with occasional gray to dark-gray flattened clay pebbles forming discontinuous laminae.	6.0

APPENDIX II. CHEMICAL AND SPECTROGRAPHIC ANALYSES

A series of wet chemical and qualitative spectrographic analyses of selected rock units were made as part of the investigation of the potential mineral resources of the Millerstown quadrangle. Seventeen samples from 13 members of 8 formations were analyzed. All but three were channel samples which were crushed and split to insure that representative samples were being analyzed. The three exceptions are samples 136-5-9, 136-4-4, and 136-8-2. Analytical techniques included wet chemical methods for the principal oxides and spectrographic testing for trace elements (the spectrographic analyses may be inaccurate). The analyses were done by E. L. Conwell Company of Philadelphia.

SAMPLE DESCRIPTIONS AND LOCATIONS

Tuscarora Formation

Sample 136-8-2: Selected samples of light-gray quartzite, upper half of the Tuscarora Formation along U.S. Route 22-322, 1.2 miles (1.9 km) north of Millerstown. Tuscarora units 1 through 30 in the Millerstown Silurian section (Appendix I, locality 1). *See Figures 4 and 5.*

Sample 136-8-3: Channel sample from the Tuscarora Formation from the above locality. Quartzite and gray shale.

Rose Hill Formation

Sample 136-7-14: Channel sample of light-olive-gray shale and siltstone from the lower shaly member, Rose Hill units 33 through 41 in the Millerstown Silurian section. Sampled along U.S. Route 22-322, 1.3 miles (2.1 km) north of Millerstown.

Sample 136-7-1: Blackish-red hematitic sandstone, Cabin Hill Member, Rose Hill unit 61 in the Millerstown Silurian section. Sampled from a prominent ledge above U.S. Route 22-322 about 2.2 miles (3.5 km) north of Millerstown. *See Figure 10.*

Sample 136-7-15: Gray shale and siltstone from the middle shaly member, Rose Hill units 62 through 77 in the Millerstown Silurian section. Sampled along the north side of U.S. Route 22-322 about 2.6 miles (4.2 km) north of Millerstown.

Sample 136-7-3: Grayish-red hematitic sandstone from the Center Member, Rose Hill units 78 through 94 in the Millerstown Silurian section. Sampled along the north side of U.S. Route 22-322, 2.7 miles (4.3 km) north of Millerstown.

Sample 136-7-16: Gray shale and limestone from the upper shaly member, Rose Hill units 92 through 102 in the Millerstown Silurian section. Sampled along the north side of U.S. Route 22-322 about 2.7 miles (4.3 km) north of Millerstown. *See Figure 9.*

Mifflintown Formation

Sample 136-7-17: Gray shale and limestone from the Mifflintown Formation, units 113 through 134 in the Millerstown Silurian section. Sampled along the north side of U.S. Route 22-322 about 2.8 miles (4.5 km) north of Millerstown. *See Figures 13 and 14.*

Bloomsburg Formation

Sample 136-1-17: Grayish-red silty claystone from the Glen Gery Corporation quarry 0.6 mile (1.0 km) south of Beavertown, Snyder County.

Channel sample from a stratigraphic interval approximately 300 feet thick, in a continuous exposure across the west end of the quarry. This section described by Hoskins (1961, p. 26-28). *See Figure 15.*

Tonoloway and Keyser Formations

Sample 136-4-4: Gray limestone, sample from the Juniata Limestone Company quarry on Lost Creek Ridge, Juniata County (Appendix I, locality 2). Composite sample taken from several piles of crushed stone in the quarry. *See Figures 18 and 19.*

Marcellus Formation

Sample 136-5-10: Grayish-black fissile shale, channel sample from a small abandoned quarry on the east side of a dirt road along the east side of Cocolamus Creek 0.3 mile (0.5 km) north of Wardville, Perry County. Section is described in the Wardville Devonian section, Appendix I, locality 3. *See Figure 25.*

Sample 136-7-13: Gray shale and siltstone from a 36-foot unit near the top of the formation. Channel samples taken from unit 1 in the Donnally Mills Devonian section (Appendix I, locality 4), Perry County.

Mahantango Formation

Sample 136-7-12: Olive-gray shale and siltstone from the lower 125 feet of the Fisher Ridge Member, Mahantango unit 1 in the Donnally Mills Devonian section, Perry County. *See Figure 28.*

Sample 136-5-8: Light-olive-gray silty claystone (composite sample) from an active quarry in the Sherman Ridge Member at Kellerville, Monroe Township, Juniata County. *See Figure 33.*

Sample 136-5-9: Sherman Ridge Member from the same locality as the above sample. Sample composed of selected fragments of light-olive-gray silty claystone with coatings of wad on fractures. The wad occurs as a bluish-black encrustation with an adamantine luster.

Sample 136-8-18: Light-olive-gray silty claystone from an active quarry in the Sherman Ridge Member at the intersection 0.9 mile (1.4 km) south of the Millerstown bridge on the west side of the Juniata River.

Harrell Formation

Sample 136-6-11: Shale, light-olive-gray to dark-olive-gray, slightly silty to very silty, moderately fissile to splintery, with occasional siltstone laminae. Channel sample from an exposure at the junction of Pa. Routes 235 and 17, 1.7 miles (2.7 km) northwest of Liverpool, Perry County. *See Figure 37.*

Chemical and Spectrographic Analyses

Wet Chemical Analyses

Formation and member	Sample number	SiO_2	TiO_2	Al_2O_3	Fe_2O_3	FeO	MnO	MgO	CaO	Na_2O	K_2O	P_2O_5	S	C
Harrell	136–6–11	64.78	0.65	14.14	3.08	1.65	0.00	1.18	0.22	0.50	3.33	0.11	0.27	3.73
Mahantango,														
Sherman Ridge Mbr.	136–8–18	59.16	0.95	20.67	5.15	0.82	0.03	1.33	0.06	0.50	4.60	0.10	0.04	0.95
do.	136–5– 9	60.20	0.99	18.21	6.05	1.72	0.12	1.44	0.12	0.65	3.67	0.08	0.03	0.39
do.	136–5– 8	61.10	0.93	17.52	5.07	2.34	0.05	1.74	1.42	0.65	3.67	0.14	0.03	0.41
Fisher Ridge Mbr.	136–7–12	63.38	0.80	14.15	3.13	2.40	0.05	1.84	0.50	0.99	2.80	0.13	0.12	0.57
Marcellus	136–7–13	66.00	0.82	14.93	4.15	0.82	0.45	0.87	0.22	0.25	3.38	0.09	0.10	2.47
do.	136–5–10	64.78	0.65	14.14	3.08	1.65	0.00	1.18	0.22	0.50	3.33	0.11	0.27	3.73
Tonoloway and Keyser	136–4– 4	6.30	—*	2.81	0.96	—	—	2.73	48.06	—	—	0.05	0.30	0.58
Bloomsburg	136–1– 7	53.08	0.86	17.38	6.87	1.16	0.07	1.75	5.66	0.30	3.74	0.12	0.00	0.13
Mifflintown	136–7–17	30.42	0.52	9.69	3.82	1.37	0.10	1.82	25.64	0.33	2.01	0.11	1.19	0.25
Rose Hill,														
Upper shaly member	136–7–16	55.54	1.11	12.03	1.79	4.47	0.19	1.88	9.03	0.42	2.23	0.17	0.22	0.21
Center Member	136–7– 3	67.32	0.86	11.06	7.05	4.20	0.17	1.47	1.32	0.34	1.92	0.30	0.00	0.08
Middle shaly member	136–7–15	60.76	0.93	18.59	5.11	2.27	0.07	1.96	0.32	0.62	3.99	0.13	0.02	0.10
Cabin Hill Member	136–7– 1	70.52	0.67	8.10	11.23	3.31	0.14	1.24	0.46	0.15	1.42	0.40	0.01	0.03
Lower shaly member	136–7–14	58.30	0.99	19.71	5.82	1.34	0.06	1.67	0.40	0.30	4.98	0.13	0.37	0.15
Tuscarora	136–8– 3	84.38	0.68	7.56	2.98	0.00	0.01	0.51	0.08	0.00	0.00	0.00	0.04	0.00
do.	136–8– 2	92.76	0.38	3.00	2.29	0.00	0.03	0.00	0.06	0.00	0.00	0.00	0.00	0.00

* Dash indicates not analyzed.

Chemical and Spectrographic Analyses (Continued)

		Wet Chemical Analyses				Semiquantitative Spectrographic Analyses (parts per million)									
Formation and member	Sample number	CO_2	H_2O— 105°C	H_2O+ 105°C	Ign. Loss*	Ba	Co	Cr†	Cu	Li	Mo	Nb	Ni†	Pb	Sn
Harrell	136–6–11	0.13	1.06	4.74	9.93	500–1000	<25	<20	<25	<50	<10	<20	<15	<50	<50
Mahantango,															
Sherman Ridge Mbr.	136–8–18	0.00	0.93	5.11	6.67	500–1000	<25	<10	<25	<50	<10	<20	<15	<50	<50
do.	136–5– 9	0.00	1.07	4.65	5.83	500–1000	<25	<20	<25	<50	<10	<20	<15	<50	<50
do.	136–5– 8	0.17	0.95	4.57	5.65	500–1000	<25	10–20	<25	<50	<10	<20	<15	<50	<50
Fisher Ridge Mbr.	136–7–12	0.02	0.92	3.52	4.93	500–1000	<25	<20	<25	<50	<10	<20	<15	<50	<50
Marcellus	136–7–13	0.10	1.14	4.66	8.07	1000–1500	<25	<20	<25	<50	<10	<20	<15	<50	<50
do.	136–5–10	0.13	1.06	4.74	9.93	500–1000	<25	<20	<25	<50	<10	<20	<15	<50	<50
Tonoloway and Keyser	136–4–4	37.64	0.07	0.81	39.47	10–100	—	<1	<1	—	—	—	<1	—	—
Bloomsburg	136–1– 7	3.83	0.72	3.68	8.43	500–1000	<25	10–20	<25	<50	<10	<20	<15	<50	<50
Mifflintown	136–7–17	20.80	0.29	1.99	22.13	500–1000	<25	<10	<25	<50	<10	<20	<15	<50	<50
Rose Hill,															
Upper shaly member	136–7–16	7.74	0.27	3.13	11.09	500–1000	<25	<10	<25	<50	<10	<20	<15	<50	<50
Center Member	136–7– 3	1.29	0.28	2.76	3.63	>100	—	<1	<1	—	—	—	<1	—	—
Middle shaly member	136–7–15	0.19	0.93	4.55	5.49	500–1000	<25	<10	<25	<50	<10	<20	<15	<50	<50
Cabin Hill Member	136–7– 1	0.41	0.26	2.30	2.50	>100	—	<1	<1	—	—	—	<1	—	—
Lower shaly member	136–7–14	0.00	1.11	5.05	6.26	500–1000	<25	<10	<25	<50	<10	<20	<15	<50	<50
Tuscarora	136–8– 3	0.07	0.13	1.83	1.87	>100	—	<1	<1	—	—	—	<1	—	—
do.	136–8– 2	0.12	0.06	0.58	0.77	>100	—	<1	<1	—	—	—	<1	—	—

* Ignition loss, nitrogen atmosphere, 1000 degrees Centigrade.

† Values for Cr, Ni, are suspiciously low.

Chemical and Spectrographic Analyses (Continued)

Semiquantitative Spectrographic Analyses (parts per million)

Formation and member	Sample number	Sr	V	Y	Yb	Zn[†]	Zr	K	Mn	Na	Ti
Harrell	136-6-11	100–200	200–300	<20–50	<10	<25	100–300	—	—	—	—
Mahantango,											
Sherman Ridge Mbr.	136-8-18	100–200	300–400	<20–50	<10	<25	100–300	—	—	—	—
do.	136-5- 9	100–200	100–200	20–50	<10	<25	100–300	—	—	—	—
do.	136-5- 8	100–200	<100	20–50	<10	<25	100–300	—	—	—	—
Fisher Ridge Mbr.	136-7-12	100–200	200–300	<20–50	<10	<25	100–300	—	—	—	—
Marcellus	136-7-13	100–200	<100	<20–50	<10	<25	100–300	—	—	—	—
do.	136-5-10	100–200	300–400	20–50	<10	<25	100–300	—	—	—	—
Tonoloway and Keyser	136-4- 4	1–10	1–10	—	—	<1	1–10	—	1–10	10–100	10–100
Bloomsburg	136-1- 7	100–200	<100	20–50	<10	<25	100–300	—	—	—	—
Mifflintown	135-7-17	100–200	<100	<20–50	<10	<25	100–300	—	—	—	—
Rose Hill,											
Upper shaly member	136-7-16	100–200	<100	<20–50	<10	<25	100–300	—	—	—	—
Center Member	136-7- 3	1–10	1–10	—	—	<1	1–10	—	—	—	—
Middle shaly member	136-7-15	100–200	<100	<20–50	<10	<25	100–300	—	—	—	—
Cabin Hill Member	136-7- 1	1–10	1–10	—	—	<1	1–10	—	—	—	—
Lower shaly member	136-7-14	100–200	300–400	<20–50	<10	<25	100–300	—	—	—	—
Tuscarora	136-8- 3	1–10	1–10	—	—	<1	1–10	>100	10–100	10–100	>100
do.	136-8- 2	1–10	1–10	—	—	<1	1–10	10–100	10–100	10–100	>100

[†] Values for Zn are suspiciously low.

APPENDIX III. PRELIMINARY CLAY EVALUATION

Since most clay products undergo high-temperature treatment (firing) in the manufacturing process, preliminary evaluation of clays and shales includes two types of firing tests.

SLOW-FIRING TEST

In this test, the temperature is raised by 525° F per hour to 1800° F, then raised by 125° F per hour to 2300° F. Samples are removed at 2000, 2100 and 2300° F and examined for color, hardness, shrinkage, absorption, specific gravity and bulk density. From these data an evaluation can be made of the suitability of the clay for specific ceramic purposes. Ceramic products are categorized into structural clay products (common brick, face brick, decorated brick, hollow tile, wall tile, drain tile, roofing tile, floor tile, flue tile, architectural terra-cotta and sewer pipe), refractory tiles and bricks, and pottery and stoneware. Each category (or each product within a category) requires particular properties of the clay and this testing procedure indicates the probable suitability of a clay for specific purposes.

QUICK-FIRING TEST

In this test, the temperature is raised rapidly to 1800° F, then held at each successive 100° F level for only 15 minutes. This procedure examines the suitability of the clay for lightweight aggregate, in particular its bloating characteristics. Desirable material bloats gradually over a wide range of temperature (more than 200° F). Samples which are indicated as possible lightweight aggregate material are usually tested further in a rotary kiln.

The characteristics of all thirteen samples, determined by both the slow-firing test and the quick-firing test, are presented in the table below. These are only preliminary results, and more extensive sampling and testing are required to prove suitability.

All samples tested are channel samples taken from the maximum stratigraphic interval of each unit exposed at each outcrop. A wet chemical analysis and spectrographic analysis of each unit are presented in Appendix II.

Slow- and Rapid-Firing Tests

Sample 136-D-Sh-11, (136-6-11)†

Harrell Formation

Locality: Roadcut on south side of intersection of Pa. Routes 17 and 235, 1.7 miles (2.7 km) northwest of Liverpool, Perry County. *See Figure 37.*

		SLOW-FIRING TEST					QUICK-FIRING TEST	
Temperature, degrees F	Color	Moh's hardness	Total shrinkage: percent of plastic length	Absorption percent	Apparent specific gravity	Bulk density	Weight lb/cu. ft.	Absorption percent
2000	Buff (5YR7/6)	2	2.5	15.4	2.60	1.86	132.3	3.2
2100	Light orange brown (5YR6/6)	3.5	3.5	12.4	2.58	1.95	104.8	4.3
2200	Red brown (2.5YR5/6)	7	5.3	8.4	2.53	2.09	102.3	5.3
2300	Dark brown (2.5YR4/2)	7+	7.0	5.2	2.42	2.15	*	—

Sample 136-C-Sh/Clyst-19

Mahantango Formation, Sherman Ridge Member

Locality: In quarry at intersection 0.9 mile (1.4 km) south of the Millerstown bridge, on the west side of the Juniata River.

Temperature, degrees F	Color	Moh's hardness	Total shrinkage: percent of plastic length	Absorption percent	Apparent specific gravity	Bulk density	Weight lb/cu. ft.	Absorption percent
2000	Light tan (7.5YR8/4)	3	3.3	15.7	2.52	1.81	111.6	3.8
2100	Dark tan (7.5YR6/4)	6	5.5	11.6	2.54	1.96	85.9	9.3
2200	Light red brown (5YR4/6)	7+	9.0	5.7	2.48	2.18	*	—
2300	Medium brown (5YR4/2)	7+	9.0	4.4	2.46	2.32		

Sample 136-C-Sh/Clyst-18, (138-8-18)

Mahantango Formation, Sherman Ridge Member

Locality: In quarry at intersection 0.9 mile (1.4 km) south of the Millerstown bridge, on the west side of the Juniata River.‡

Temperature, degrees F	Color	Moh's hardness	Total shrinkage: percent of plastic length	Absorption percent	Apparent specific gravity	Bulk density	Weight lb/cu. ft.	Absorption percent
2000	Light tan (7.5YR8/4)	3	4.5	13.7	2.52	1.87	124.8	3.2
2100	Dark tan (7.5YR6/4)	7+	7.3	9.3	2.56	2.06	105.5	4.3
2200	Light red brown (5YR4/6)	7+	9.8	3.8	2.46	2.25	68.6	4.8
2300	Medium brown (5YR4/2)	7+	9.8	1.9	2.36	2.26	*	—

Sample 136-A-Sh-8,
(136-5-8)

Mahantango Formation, Sherman Ridge Member
Locality: Quarry at Kellerville, Juniata County.

2000	Light orange brown (5YR6/6)	3	5.8	13.9	2.59	1.90	125.4	13.9
2100	Light red brown (5YR4/4)	7+	10.0	7.8	2.52	2.11	137.3	8.6
2200	Medium red brown (2.5YR4/4)	7+	10.0	3.2	2.46	2.28	131.7	9.6
2300	Dark brown (2.5YR4/2)	7+	11.0	3.2	2.38	2.21	129.2	5.4
2000	Orange brown (5YR6/8)	3	2.3	15.1	2.53	1.83	113.6	5.8
2100	Light red brown (5YR4/6)	6	4.3	11.1	2.51	1.97	79.9	10.2
2200	Brown red (10R4/4)	7+	5.3	8.7	2.40	1.99	*	—
2300	Dark brown (2.5YR4/2)	7+	1.3	8.6	2.01	1.72		

Sample 136-C-Sh-20

Marcellus Formation
Locality: Approximately 0.4 mile (0.6 km) south of Donnally Mills, Perry County, on west side of road.
Unit 9, Donnally Mills section, Appendix I, locality 5.

2000	Light tan (7.5YR8/4)	2	4.0	16.4	2.52	1.79	145.4	5.9
2100	Medium tan (7.5YR7/4)	5	5.0	14.3	2.56	1.87	141.6	4.3
2200	Dark tan (7.5YR6/4)	7	5.3	11.4	2.47	1.93	117.9	3.7
2300	Gray brown (7.5YR5/2)	7+	7.8	8.5	2.48	2.05	123.6	3.2

Sample 136-C-Sh-13,
(136-7-13)

Marcellus Formation
Locality: Approximately 0.3 mile (0.5 km) south of Donnally Mills, Perry County, on west side of road.
Unit 1, Donnally Mills section, Appendix I, locality 5.

2000	Light tan (7.5YR8/4)	4.5	4.8	15.6	2.52	1.81	107.9	6.6
2100	Medium tan (7.5YR7/4)	6.5	7.3	11.8	2.45	1.90	94.8	6.0
2200	Dark tan (7.5YR6/4)	7+	9.3	6.5	2.39	2.07	104.8	8.3
2300	Gray brown (7.5YR5/2)	7+	9.3	3.2	2.31	2.15	*	—

Slow- and Rapid-Firing Tests (Continued)

Sample 136-C-Sh-10, (136-5-10)

Marcellus Formation

Locality: Small quarry on east side of dirt road 0.3 mile (0.5 km) north of Wardville, Perry County, on east side of Cocolamus Creek. Unit 23, Wardville Devonian section, Appendix I, locality 3. *See Figure 25.*

		SLOW-FIRING TEST					QUICK-FIRING TEST	
Temperature, degrees F	Color	Moh's hardness	Total shrinkage: percent of plastic length	Absorption percent	Apparent specific gravity	Bulk density	Weight lb/cu. ft.	Absorption percent
2000	Light orange brown (5YR6/6)	3	2.8	22.6	2.47	1.59	127.3	7.7
2100	Light red brown (5YR4/4)	5	3.3	18.1	2.44	1.69	121.1	10.6
2200	Medium red brown (2.5YR4/4)	7+	7.8	13.1	2.04	1.81	79.2	12.2
2300	Dark brown (2.5YR4/2)	7+	5.4	11.1	2.09	1.88	*	—

Sample 136-A-Clyst-7, (136-1-7)

Bloomsburg Formation

Locality: The Glen Gery Corporation quarry 0.6 mile (1.0 km) south-southwest of Beavertown, Snyder County. *See Figure 15.*

Temperature, degrees F	Color	Moh's hardness	Total shrinkage: percent of plastic length	Absorption percent	Apparent specific gravity	Bulk density	Weight lb/cu. ft.	Absorption percent
2000	Light red brown (2.5YR5/4)	4	5.5	16.7	2.54	1.79	127.3	10.9
2100	Light red brown (5YR4/4)	7	7.0	14.5	2.56	1.86	128.5	4.3
2200	Medium red brown (2.5YR4/4)	7+	10.0	6.0	2.42	2.11	104.2	1.6
2300	Dark red brown (2.5YR2/2)	7+	7.8	0.0	1.74	1.74	*	—

Sample 136-C-Ls/Sh-17, (136-7-17)

Mifflintown Formation

Locality: Roadcut on north side of U.S. Route 22-322, approximately 2.8 miles (4.5 km) northwest of Millerstown, Juniata County. Millerstown Silurian section, Appendix I, locality 1. *See Figure 14*

Temperature, degrees F	Color	Moh's hardness	Total shrinkage: percent of plastic length	Absorption percent	Apparent specific gravity	Bulk density	Weight lb/cu. ft.	Absorption percent
2000	Medium tan (7.5YR7/4)	2	2.8	26.8	2.81	1.60	**	
2100	Light gray white (10YR8/2)	3	2.8	25.5	2.64	1.58		
2200	Gray brown (2.5YR5/4)	5	2.8	22.6	2.65	1.66		
2300	Black (10YR3/1)	7+	***	***	***	***		

Sample 136-C-Sh-16, (136-7-16)

Rose Hill Formation, Upper shaly member
Locality: Roadcut on north side of U.S. Route 22-322, approximately 2.7 miles (4.3 km) northwest of Millerstown, Juniata County. Millerstown Silurian section, Appendix I, locality 1. *See Figure 9.*

2000	Light red brown (2.5YR6/4)	1	1.3	26.8	2.78	1.59	128.5	7.3
2100	Medium brown (5YR5/4)	2	1.3	20.0	2.62	1.72	112.3	9.0
2200	Medium red brown (2.5YR4/4)	7	1.8	14.1	2.46	1.75	82.4	12.9
2300	Dark gray (5YR3/1)	7+	***	***	***	***	*	*

Sample 136-C-Sh-15, (136-7-15)

Rose Hill Formation, Middle shaly member
Locality: Roadcut on north side of U.S. Route 22-322, approximately 2.6 miles (4.2 km) northwest of Millerstown, Juniata County. Millerstown Silurian section, Appendix I, locality 1.

2000	Orange brown (5YR5/6)	3	4.8	11.0	2.61	2.02	146.0	2.1
2100	Light red brown (5YR4/4)	7+	6.8	7.6	2.58	2.15	112.3	3.3
2200	Medium red brown (2.5YR4/4)	7+	8.8	3.0	2.55	2.37	98.6	3.2
2300	Dark brown (5YR4/2)	7+	9.3	2.3	2.38	2.25	*	—

Sample 136-C-Sh-14, (136-7-14)

Rose Hill Formation, Lower shaly member
Locality: Roadcut on north side of U.S. Route 22-322, approximately 1.3 miles (2.1 km) northwest of Millerstown, Juniata County.‡

2000	Buff (5YR7/6)	4	5.0	10.5	2.63	2.06	142.9	1.6
2100	Light orange brown (5YR6/6)	7+	6.8	6.2	2.60	2.24	122.3	2.2
2200	Red brown (2.5YR5/6)	7+	8.3	2.9	2.54	2.37	79.9	5.9
2300	Dark brown (2.5YR4/2)	7+	5.3	0.0	2.11	2.11	*	—

* Pyroplastic mass.

** No quick-fires performed because of the short firing range of the shale.

*** Nonmeasurable.

† Number in parentheses refers to chemical analysis (Appendix II).

‡ Potential commercial use. See text for discussion.

APPENDIX IV

A. WATER WELL RECORDS

(Data from drillers' water well completion reports on file at the Pennsylvania Geological Survey and from earlier reports in Lohman, 1938)

Well number: Letter prefix indicates county in which well is located. Number relates record in this table to well's location on Plate 5.

Topographic location: D, drainage divide; H, hilltop; S, slope; V, valley bottom.

Driller: JEH, John Hockenberry, Landisburg, Pa.; JMH, J. M. Hubler, Port Royal, Pa.; K, Kohl Bros., Harrisburg, Pa.; Z, Zechman Bros., Middleburg, Pa.

Accuracy of location: 1, within 100 ft.; 2, within 1,000 ft.; 4, within 1 mile. Locations were furnished by drillers and well owners, and in most cases have not been checked in the field.

Elevation: Estimated from topographic maps.

Aquifer: Mpm, Pocono Formation, Mount Carbon Member; Dcd, Catskill Formation, Duncannon Member; Dcs, Catskill Formation, Sherman Creek Member; Dci, Catskill Formation, Irish Valley Member; Dth, Trimmers Rock and Harrell Formations; Dms, Mahantango Formation, Sherman Ridge Member; Dmm, Mahantango Formation, Montebello Member; Dmf, Mahantango Formation, Fisher Ridge Member; Dmr, Marcellus Formation; Don, Onondaga Formation; SDk, Keyser Formation; Sto, Tonoloway Formation; Sw, Wills Creek Formation; Sb, Bloomsburg Formation; Sm, Mifflintown Formation; Sr, Rose Hill Formation.

Reported lithology of aquifer: Ls, limestone; Sh, shale; Ss, sandstone.

Water use: D, domestic; I, industrial; N, none; P, public water supply; S, stock.

Well number	Township	Well owner	Topographic location	Driller	Accuracy of location	Date completed	Elevation	Casing diameter (inches)	Casing length (feet)	Total depth (feet)	Depth to bedrock (feet)	Depth to water-bearing zones (feet)	Aquifer	Reported lithology of aquifer	Static water level (feet below the land surface)	Reported yield (gpm)	Specific capacity of well (No. of ft. drawdown/yield in gpm)	Water use
JUNIATA COUNTY																		
JU-3	Delaware	J. H. Wirt	V?	JMH	4	3/68	590′	5⅝	34	57	28	40, 51	Sto	Ls	27	14	—	D
JU-13	Delaware	K. Leach	S	Z	1	6/66	650	6¼	44	147	85	122, 140	Dmm	Sh	—	7	—	D
JU-14	Delaware	Ray T. Benner	V	Z	1	6/67	490	8¾	102	190	90	135, 160	Sto	Sh	60	150	—	D
JU-26	Delaware	Zigler	S	Z	1	9/66	695	6¼	58	172	55	90, 140, 166	Dmm	Sh	35	10	—	D

JU-38	Delaware	Jacob Kauffman	V	Z	1	4/69	550	6¼	40	122	16	70, 112, 115	SDk	Ls	6	20	—	D
JU-39	Delaware	Gerald Swartz	D	Z	1	4/69	848	6¼	80	122	73	85, 110	Dmm	Ls	—	7	—	D
JU-40	Delaware	Philip C. Varner	V	Z	1	11/66	555	6¼	156	197	146	160, 183, 190	Sto	Sh	50	10	—	D
JU-41	Delaware	Harmon Begrade	D	Z	1	12/61	848	6¼	87	122	80	90, 109, 118	Dmm	Sh	50	6	—	D
JU-101	Delaware	William Gilpin	V	Z	2	1/70	595	6¼	42	396	35	150, 305, 350	Dms	Sh	—	5	—	D
JU-104	Delaware	J. M. Graybill	V?		4	1934	620	6	22	40			Dmf	Sh, Ss	3	3	—	D
JU-105	Delaware	T. Hubbard	V?		4	1934	650	6	24	74			Dms	Gy Sh	35	1½	—	S
JU-106	De'aware	Ralph Freed	S?		4	1934	700	6	18	85			Dmm	Blk Sh	45	2	—	D
JU-107	Delaware	M. E. Schlegal	V?		4	1934	460	6		45			Sto	Ls	8	3	—	N
JU-108	Delaware	Breyer Ice Cream	V?		4	1934	430	6	20	180		100	Sw	Ls	2	"large"	—	N
JU-109	Delaware	Thompson Water Works	V?		4	1934	640	6		70			Dmm	Blk Sh	0–2	30	1.50	N
JU-4	Fayette	John Schell	V?	JMH	4	11/67	670	5⅝	20	56	16	31, 44	Sto	Ls	10	15	—	D
JU-6	Fayette	J. H. Wirt	V	JMH	2	3/68	675	5⅝	30	54	21	36, 48	Sto	Ls	20	12	—	D
JU-7	Fayette	Chester Landis	V	JMH	2	9/68	670	5⅝	18	48	12	31, 47	Sto	Ls	20	12	—	D
JU-8	Fayette	Phyllis Hepner	V	JMH	2	1/67	640	6	16	28	10	18, 27	Dmr	Ss	11	20	—	D
JU-36	Fayette	Ken Hepner	S	Z	1	7/68	810	6¼	60	397	55	211, 363, 393	Sm	Ls	—	4	—	D
JU-37	Fayette	Roy Smith	V	Z	1	11/67	715	6⅝	62	147	55	72, 122, 130	Don	Sh, Ls	50	5	—	D
JU-110	Fayette	J. D. Lefher	V?		4	1934	640	6	20	44			Don	Ls	24	3	—	D
JU-111	Fayette	Mrs. Scholl	V?		4	1934	700		6	94			Sw	Calc. Sh	—	3	—	D
JU-1	Greenwood	Troup Bros. & Benner	V	JMH	1	9/68	575	5⅝	20	74	12	40, 65	Dms	Sh	20	9	1.80	I
JU-2	Greenwood	D. P. Fisher	V	JMH	2	8/68	565	5⅝	20	46	12	32. 44	Dms	iron rock	10	6	—	D
JU-113	Greenwood	Claude Swartz	H?		4	1934	830	6	22	135			Dth	Sdy Sh	100	1–3		D, S
JU-114	Greenwood	Troup Bros.	V?		4	1934	560	6	10	40			Dms	Sh	10	2	—	D
JU-9	Monroe	Adam Fogle	H?	JMH	4	11/67	960	5⅝	33	86	18	45, 80	Dcl	Slate	40	7	—	D
JU-10	Monroe	Chas. Bollinger	V?	JMH	4	6/68	700	5⅝	23	60	13	27, 52	Dth	Sh	22	10	1.25	D
JU-11	Monroe	Glen L. Kauffman	V	Z	1	5/68	650	6¼	43	462	25	206, 413	Dth	Sh	110	2	—	D
JU-15	Monroe	J. A. Strawser	V	Z	1	2/69	635	6¼	43	122	29	62, 93, 112	Dth	Ls		50	-	D
JU-16	Monroe	J. Beaver	S	Z	2	1/68	840	6¼	40	247	30	48, 190, 242	Dci	Sh		5	—	D
JU-17	Monroe	G. R. Matthews	V	Z	1	7/67	760	6¼	40	112	10	61, 103	Dth	Ls	full	80	—	D
JU-18	Monroe	Earl Pyle	H	Z	1	2/67	850	6¼	42	172	36	47, 95, 158	Dci	Sh	40	5	—	D
JU-21	Monroe	G. Matthews	S	Z	2		760	6⅝	20	97	10	47	Dth	Sh	10	50	—	D
JU-22	Monroe	Keith Shaffer	V?	Z	4	12/68	675	6¼	63	147	55	73, 83, 140	Dth	Sh		7	—	D
JU-24	Monroe	Leon Miller	V	Z	1	7/66	665	6	76	122	73	82, 120	Sto	Ls		90	—	D
JU-30	Monroe	Mary Lauver	V	Z	1	6/66	710	6¼	38	97	30	87, 90	Sto	Sh	11	20	—	D
JU-42	Monroe	J. Buckley	S?	Z	4	3/67	800	6¼	33	141	30	132, 141	Dci	Gy Sh		?	—	D
JU-102	Monroe	Paul Strawser	V	Z	1	2/68	605	6¼	40	197	6	97, 170, 190	Dci	Sh	11	20	—	D

A. WATER WELL RECORDS (*Continued*)

Well number	Township	Well owner	Topographic location	Driller	Accuracy of location	Date completed	Elevation	Casing diameter (inches)	Casing length (feet)	Total depth (feet)	Depth to bedrock (feet)	Depth to water-bearing zones (feet)	Aquifer	Reported lithology of aquifer	Static water level (feet below the land surface)	Reported yield (gpm)	Specific capacity of well (No. of ft. draw-down/yield in gpm)	Water use
JU-120	Monroe	A. C. Goodling	V?		4	1934	720	6		30			Sw	Calc. Sh		3	—	D
JU-103	Susquehanna	Roy Stahr	V	Z	2	3/70	510	6¼	61	147	12	68, 91, 130	Dms	Ls & Sh	20	20	—	D
JU-115	Susquehanna	D. W. Goodling	S?		4	1934	760	6	20	136			Dth	Ss	75	6	—	D
JU-116	Susquehanna	D. W. Goodling	V?		4	1934	600	6	15	44			Dth	Sh	7	3	0.10	D
JU-117	Susquehanna	D. W. Goodling	S?		4	1934	560	6	15	36			Dth	Blk Sh	0–3	1–3	—	D
JU-118	Susquehanna	Calvin Goodling	V?		4	1934	470	6	17	46			Dms	Blue Sh	17	2	—	D
JU-119	Susquehanna	C. J. Strawser	V?		4	1934	480	6	15	42			Dth	Blue Sh	full	5–6	0.20	D
								PERRY COUNTY										
PE-26	Buffalo	Howard Cover	S?	K	4	7/66	550	6¼	32	138	25	60, 118	Dci	Ss, Rd Sh	40	15	0.15	D
PE-17	Greenwood	Gwen Fashions	S	Z	2	7/66	450	6	48	197	25	140, 190	Dci	Red rock		25	—	D
PE-23	Greenwood	Leslie Byers	S	K	1	7/66	435	6¼	28	398	20	200, 300	Dcd	Ss, Sh	110	7	0.02	D
PE-30	Greenwood	C. R. Markle	V	JEH	2	8/66	640	5⅝	23	104	104	65, 102	Dcd	Red Ss	45			D
PE-143	Greenwood	T. Goodling	S	Z	2	8/69	850	6	40	172	25	95, 145	Dmm	Black rock	45	5	—	D
PE-163	Greenwood	R. McDonald	H?		4	1934	560	6	12	124			Sw	Blk Sh	30	10	1.06	D
PE-164	Greenwood	Ian Zeigler	V?		4	1934	450	6	26	41			Sr	Red & blue Sh	10	15	0.90	D
PE-165	Greenwood	I. L. Zeigler	V?		4	1934	460	48	12½	12½			Sw	Sh	3–5	?	—	N
PE-166	Greenwood	Charles Lidick	H?		4	1934	660	6	20	100			Dth	Sh	30	4	0.20	D
PE-22	Howe	Newport Boro. Water Authority	V	K	2	5/66	700	12, 8	22, 47	350	20	54, 67	Mpm	Ss	24	75	0.43	P
PE-2	Liverpool	J. S. Charles	V	Z	1	3/69	500	6¼	64	176	48	115, 150, 170	Dcs	Ss		6	—	D
PE-3	Liverpool	John Doe	V	Z	1	7/66	580	6¼	45	147	40	85, 120, 140	Sto	Sh	40	12	—	D
PE-11	Liverpool	John Ward	V	Z	1	7/66	475	6	20	103	10	90, 100	Dcd	Red rock		12	—	D
PE-13	Liverpool	John Hettrick	H	Z	1	6/66	525	6¼	4	172	30	130, 152, 168	Dcd	Sh	30	7	—	D
PE-15	Liverpool	Russell Rubendoll	V	Z	1	6/66	520	6¼	32	97	28	70, 92	Dcs	Sh	15	20	—	P
PE-16	Liverpool	Lions Club	S	Z	1	5/66	520	6	42	68	41	45	Dcd	Red rock	—	25	—	D

PE-24	Liverpool	C. E. Earnest	V	K	1	6/69	495	6¼	29	80	20	29	Dcs	Ss	35	7	0.16	D
PE-31	Liverpool	R. H. Markle	S		2	?	720	5⅝	40	89		30, 60. 80	Dci	Black slate & granite	15	20	—	—
PE-146	Liverpool	Larry Brookhard	V	K	2	8/69	625	6¼	32	110	25	50, 95	Dth	Blue slate	10	20	0.20	D
PE-167	Liverpool	H. E. Rubendoll	V?		4	1934	540	6	20	62			Dci	Red Sh	20	3	—	D, S
PE-19	Oliver	Robert Shull	S	Z	1	11/66	440	6¼	23	101	12	40, 68, 90	Dcd	Ls & red rock	40	10	—	D
PE-1	Tuscarora	Park Hubbert	V	JMH	2		495	5⅝	36	51	30	41, 48	SDk	Ls	21	10	—	D
PE-25	Tuscarora	C. D. Shaffer	S	K	1		475	6¼	24	120	12	60. 110	Sto	Sh	25	7	0.07	D
PE-157	Tuscarora	E. D. Shull	S	K	2		575	6¼	41	120	35	10, 110	Sb	Red Sh & Ss	20	30	0.30	D
PE-168	Tuscarora	Dr. Gearhard	S		4	1934	560	6	?	70			Sw					D, S
PE-169	Tuscarora	W. R. Reynolds	V		4	1934	500	6	?	50			Sto					D
								SNYDER COUNTY										
SN-3	Perry	George Stahr	S	Z	1	10/68	600	6¼	41	147	24	70, 84, 133	Don	Sh		8	—	D
SN-7	Perry	Carson Howell	V	Z	1	5/68	590	6¼	64	122	55	18, 93. 111	Sto	Sh		45	—	D
SN-11	Perry	John H. Bollinger	V	Z	1	3/68	525	6¼	35	147	12	70, 90, 135	Dms	Sh		6	—	D
SN-23	Perry	Ardell Lanau	V	Z	1	7/66	590	6¼	138	147	130	140	SDk	Sh	20	20	—	D
SN-25	Perry	Dallas Shrawder	V	Z	1	6/66	530	6	21	42	8	35	Dmf	Sh		18	—	D
SN-27	Perry	Hugh Peters	S	Z	1	5/66	665	6	33	122	15	70, 95	Sb	Red rock		10	—	D
SN-280	Perry	Mrs. Landis	V	Z	2	4/69	605	6¼	136	148	132	138	Sto	Sh	41	40	—	D
SN-281	Perry	Bruce Cryst	H	Z	2	9/69	570	6	20	72	10	60	Dmr	Blk Sh	35	12	—	D
SN-282	Perry	Edwin Moyer	D	Z	1	11/69	595	6¼	112	148	105	120, 145	Dmr	Blk Sh		15	—	D
SN-283	Perry	Alfred Reed	V	Z	1	10/69	550	6	43	72	15	60	Don	Ls	14	25	—	D
SN-284	Perry	Allen Martin	S	Z	1	9/69	540	6	25	97	5	60, 85	Dmr	Blk Sh	15	15	—	D
SN-308	Perry	C. Hockenbrock	V	Z	1	5/66	475	6	31	223	17	45, 210	Dth	Sh		5	—	D
SN-310	Perry	St. James Church	V	Z	1	7/66	565	6¼	21	97	17	25, 38, 90	Dci	Sh	10	8	—	D
SN-311	Perry	Norman Stahr	V	Z	1	6/69	475	6	42	147	15	130	Dms	Gy Sh	35			D
SN-313	Perry	Marlin Sierer	V	Z	2	3/70	590	6¼	40	122	8	60, 72, 90	Dmr	Sh	full	35	—	D
SN-314	Perry	John C. Boyer	S?		4	1934	590	6	25	79			Don	Ls	18	5	0.50	P
SN-315	Perry	John C. Boyer	S?		4	1934	620						Don	Ls		2	—	P
SN-316	Perry	Stewart S. Teats	S?		4	1934	720	6	16	60			Dms	Blue Sh	10	7½	—	S
SN-317	Perry	Stewart S. Teats	S?		4	1934	540	6	14	42			Dth	Blue Sh	22	1	—	D
SN-29	Spring	Robert Etzler	S	Z	1	5/68	940	6¼	43	72	16	53, 60, 66	Sr	Sh		15	—	D
SN-30	Spring	Carl Dressler	V	Z	1	4/68	640	6¼	65	97	60	73, 90	Sw	Sh		20	—	D

A. WATER WELL RECORDS (*Continued*)

Well number	Township	Well owner	Topo-graphic location	Driller	Accu-racy of lo-cation	Date com-pleted	Eleva-tion	Casing diameter (inches)	Casing length (feet)	Total depth (feet)	Depth to bed-rock (feet)	Depth to water-bearing zones (feet)	Aquifer	Reported lithology of aquifer	Static water level (feet below the land surface)	Re-ported yield (gpm)	Specific capacity of well (No. of ft. draw-down/yield in gpm)	Water use
SN-35	Spring	Leo Haines	V	Z	2	5/67	605	6¼	56	97	47	58, 63, 90	Sto	Sh		45	—	D
SN-112	Spring	Truman C. Storo	V	Z	2	9/66	640	6¼	36	272	10	45, 215, 265	Sw	Sh	30	10	—	D
SN-250	Spring	Edward Stracke	V	Z	1	8/69	675	6¼	62	247	50	87, 135, 244	Sto	Ls	60	6	—	D
SN-318	Spring	W. J. Treaster	S		4	1934	700	6	26	95			Sto	Flinty Ls	27	5	—	D, S
SN-4	Washington	Leroy Healey	S	Z	1	8/68	725	6¼	21	201	8	95, 137	Sm	Ls	4	4	—	D
SN-8	West Perry	Garman	S	Z	1	7/66	845	6	106	322	93	218, 310	SDk	Ls		8	—	D
SN-9	West Perry	Peron Hummel	S	Z	1	11/68	695	6¼	83½	122	79	89	Sw	Ls		?	—	D
SN-13	West Perry	R. Waganseller	V	Z	1	11/67	765	6⅝	100	172	97	120. 135, 160	Sto	Blk Sh		5	—	D
SN-36	West Perry	Warren Chubb	V	Z	1	5/68	670	6¼	65	97	60	70. 83, 90	Sto	Sh		60	—	D
SN-37	West Perry	Stanley Letzel	S	Z	1	10/67	710	6⅝	65	147	61	97, 115, 130	Sto	Ls	30	7	—	D
SN-38	West Perry	Norman E. Minium	V	Z	1	?	595	6	34	147	20	90, 110, 130	Dth	Gy Sh	45	6	—	D
SN-39	West Perry	William Brown	V	Z	1	7/67	595	6¼	40	172	10	59, 125, 168	Dth	Sh	full	200	—	D
SN-41	West Perry	George Johnson	V	Z	1	9/66	740	6¼	71	97	65	85. 90	Sto	Sh		30	—	D
SN-220	West Perry	Larry Osgood	S	Z	4	8/68	610	6¼	40	197	8	110, 173, 175	Dth	Sh	20	25	—	D
SN-306	West Perry	C. W. Wilhoor	V	Z	2	4/69	660	6¼	40	97	30	55, 73, 90	Sto	Sh & Ls		20	—	D
SN-307	West Perry	Mrs. Beular Arbogast	S	Z	1	1/69	630	6¼	46	226	23	88, 211	Dth	Sh		20		
SN-309	West Perry	Melvin Walters	D	Z	1	5/68	725	6¼	45	97	30	60, 81	Sto	Sh		50	—	D
SN-312	West Perry	Raymond Smith	V	Z	1	6/67	765	6⅝	20	72	12	52, 64, 69	Sb	Hard Sh	18	7	—	D
SN-319	West Perry	Amon Reichenback	V?		4	1934	660	6	18	55			Sto	Ls	0–15	3–5	—	D
SN-320	West Perry	J. O. Pellman	D?		4	1934	700	6	63	73			Sto	Ls	53	1½	—	D
SN-321	West Perry	Mrs. Frank Hoffman	S?		4	1934	710	6	18	62			Dms	Gy Sh	30	1	—	S

B. HYDROLOGIC CHARACTERISTICS OF INDIVIDUAL ROCK UNITS[1]

(Based on data from Part A, *Water Well Records*)

Formation/member	Dominant rock types	Number of wells	Elevation (in feet)		Depth (in feet)			Depth to bedrock (in feet)		Average depth to water-producing zones (in feet)			Average depth to static water level (in feet)	Yield (in gallons per minute)			Average specific capacity (gpm per foot of draw-down)	Map symbols (Plates 1 and 5)
			Range	Average	Range	Average	Median	Range	Average	Shallowest	Second zone	Deepest		Range	Average	Median		
Pocono Fm., Mount Carbon Mbr.	Conglomerate and sandstone	1	—	700	—	350	350	—	20	54	67	—	24	—	75	75	—	Mpm
Catskill Fm., Duncannon Mbr.	Sandstone, siltstone, and claystone	6	435–640	506	68–398	158	103	10–104	36	95	120	129	56	7–25	12	10	0.02	Dcd
Catskill Fm., Sherman Creek Mbr.	Sandstone, siltstone, and claystone	3	495–520	505	80–176	118	97	20–48	32	71	121	170	25	6–20	11	7	0.16	Dcs
Catskill Fm., Irish Valley Mbr.	Sandstone, siltstone, and claystone	10	450–960	688	41–247	133	117	6–36	23	99	120	148	25	3–25	12	8	0.15	Dci
Trimmers Rock-Harrell Fms.	Sandstone, siltstone, and shale	19	475–820	640	36–462	137	122	8–29	20	77	152	145	30	1–200	26	6	0.39	Dth
Mahantango Fm., Sherman Ridge Mbr.	Siltstone and claystone	11	470–720	577	40–396	124	74	12–35	16	81	119	208	21	1–20	6	6	1.80	Dms
Montebello Mbr.	Sandstone and siltstone	7	640–848	748	70–147	127	122	25–85	63	96	125	141	35	2–30	10	7	1.50	Dmm
Fisher Ridge Mbr.	Shale and claystone	2	530–620	575	40–42	41	41	—	8	35	—	—	3	3–18	10	10	—	Dmf
Marcellus Fm.	Shale	5	540–640	587	28–148	93	97	5–105	28	63	82	90	15	15–35	26	28	—	Dmr
Onondaga Fm.	Limestone and shale	6	550–715	619	42–146	81	72	15–55	31	67	103	132	24	2–25	8	5	0.50	Dci
Keyser Fm.	Limestone	4	495–845	620	51–322	140	134	16–130	67	117	157	115	16	8–20	14	15	—	SDk
Tonoloway Fm.	Limestone	26	460–765	622	45–247	108	97	12–146	53	77	95	138	28	2–150	27	14	0.08	Sto

B. HYDROLOGIC CHARACTERISTICS OF INDIVIDUAL ROCK UNITS (*Continued*)

Formation/member	Dominant rock types	Number of wells	Elevation (in feet)		Depth (in feet)			Depth to bedrock (in feet)		Average depth to water-producing zones (in feet)			Average depth to static water level (in feet)	Yield (in gallons per minute)			Average specific capacity (gpm per foot of draw-down)	Map symbols (Plates 1 and 5)
			Range	Average	Range	Average	Median	Range	Average	Shallowest	Second zone	Deepest		Range	Average	Median		
Wills Creek Fm.	Shale	9	430–720	600	13–272	103	97	10–79	50	77	152	265	16	—	9	—	—	Sw
Bloomsburg Fm.	Sandstone and claystone	3	575–765	668	72–122	105	120	12–35	21	44	90	69	19	7–30	16	10	0.30	Sb
Mifflintown Fm.	Shale and limestone	2	725–820	767	201–397	299	299	8–55	32	153	250	393	4	—	4	4	—	Sm
Rose Hill Fm.	Sandstone, shale, and limestone	2	450–940	695	41–72	56	56	—	16	53	60	66	10	—	15	15	0.90	Sr
All formations:		116	430–960	628	13–462	122	102	5–146	37	79	121	142	27	1–200	18	10	0.52	

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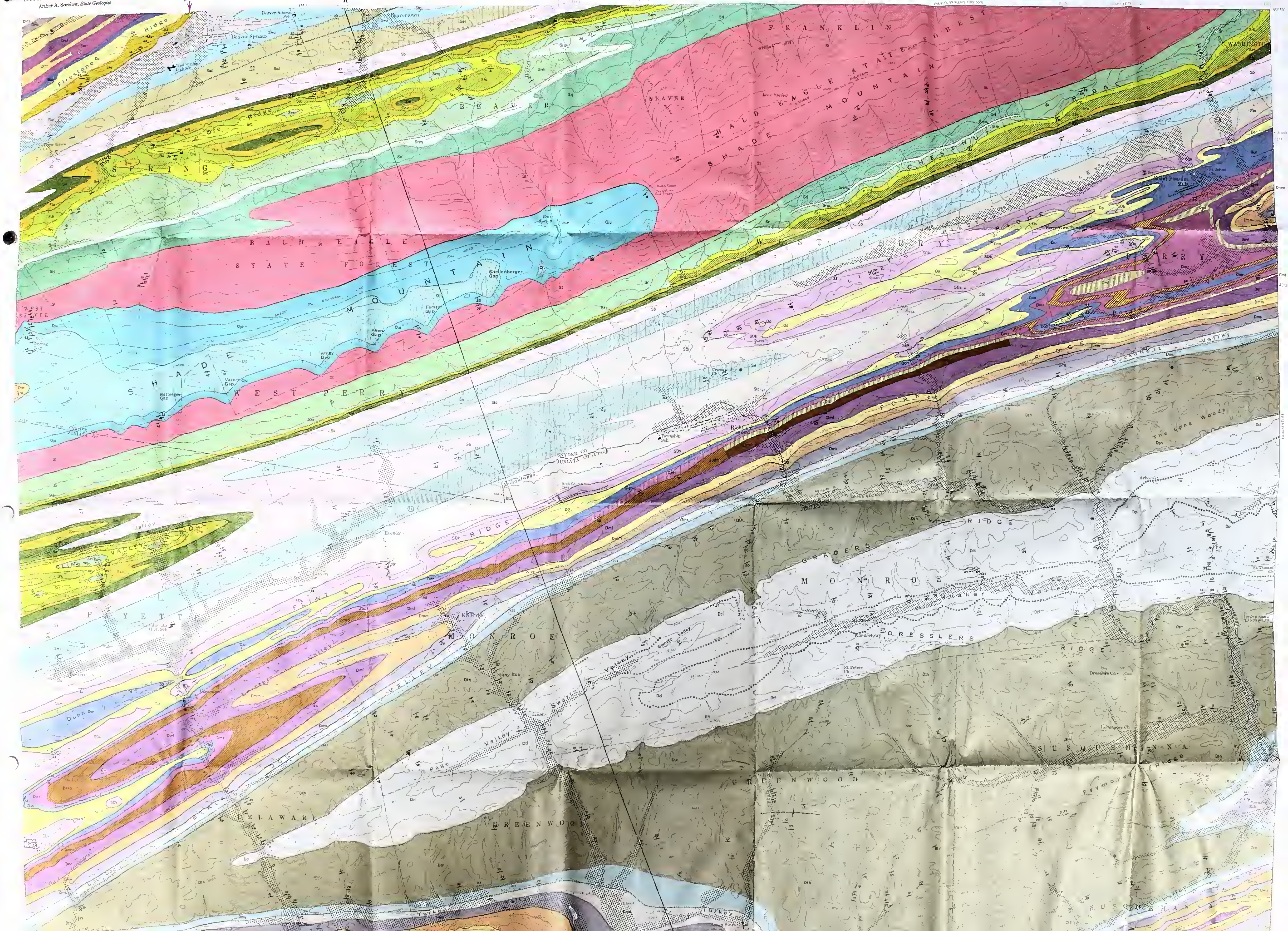
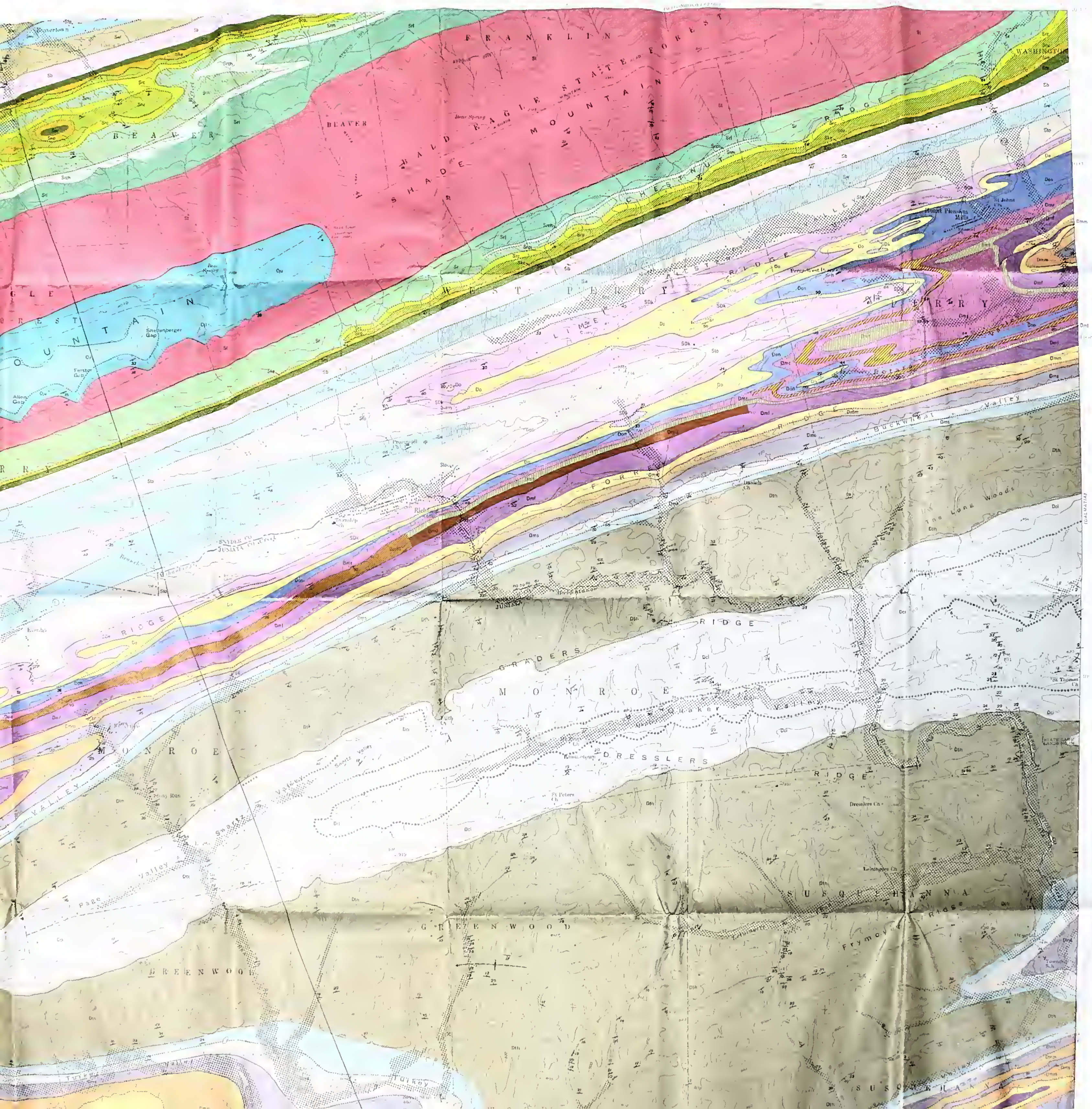
[1] There were no water well data for the following units at the time this report was prepared: Mauch Chunk Formation (Mmc), Beckville (Mpb) and Spechty Kopf (DMps) Members of Pocono Formation, Dalmatia (Dmd) and Turkey Ridge (Dmt) Members of Mahantango Formation, Old Port Formation (Do), Keefer Formation (Ske), Tuscarora Formation (St), Juniata Formation (Oju and Ojl), and Bald Eagle Formation (Obe).

TOPOGRAPHIC AND GEOLOGIC SURVEY
Arthur A. Socolow, *State Geologist*

COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF ENVIRONMENTAL RESOURCES





EXPLANATION

LITHOLOGIC DESCRIPTION

ENGINEERING, MINERAL-RESOURCE, AND GROUND-WATER CHARACTERISTICS

MISSISSIPPIAN

Middle Mississippian

Mmc

MAUCH CHUNK FORMATION

Grayish-red and gray argillaceous siltstone and silty shale; gray, medium- to coarse-grained, crossbedded conglomeratic sandstone and light-gray quartz-pebble conglomerate in lower part; 2,000+ feet (610+ m) thick.

Forms rolling valleys of low to moderate relief; moderate to fairly steep natural slopes; good surface drainage. Low to moderate resistance to weathering; weathered mantle moderate to thick. Fractures poorly developed, with wide spacing. Excavation easy to moderate; cut-slope stability poor to moderate; foundation stability fair to moderate. Good source for general fill. Ground water probably good quality, with fair yields.

Lower Mississippian

Mpm
Mpb
DMps

POCONO FORMATION

Mount Carbon Member (Mpm)—*Gray to buff, medium-grained, medium- to very thick bedded, crossbedded sandstone with beds and lenses of white quartz-pebble conglomerate in lower part; 840 feet (256 m) thick.*

Beckville Member (Mpb)—*Gray to buff, medium-grained, medium- to very thick bedded, crossbedded sandstone with beds and lenses of white quartz-pebble conglomerate in lower part; includes a few rare thin coal seams; 225 feet (69 m) thick.*

Spechty Kopf Member (DMps)—*Gray, fine- and medium-grained sandstone and dark-gray argillaceous siltstone; prominent conglomerate beds near middle and base; 435 feet (133 m) thick.*

Forms ridges and mountains of high relief; fairly to very steep natural slopes; good surface drainage. Very high resistance to weathering; weathered mantle thin to thick, bouldery. Fractures well developed, with wide spacing. Excavation difficult, blasting required; cut-slope stability very good; foundation stability excellent. Adequate source for building stone. Ground-water quality good, occasional high iron content; good yields from wells.

Upper Devonian

Dcd
Dcs
Dci

CATSKILL FORMATION

Duncannon Member (Dcd)—*Asymmetric upward-fining cycles in which a basal gray, fine- to medium-grained, locally conglomeratic sandstone is overlain by very fine grained grayish-red sandstone, grayish-red siltstone, and red silty claystone; cycles have erosional basal surfaces, 1,900 to 3,000 feet (579 to 914 m) thick.*

Sherman Creek Member (Dcs)—*Dominantly grayish-red silty claystone, siltstone, and very fine grained crossbedded sandstone, with a prominent medium-gray, very fine to medium-grained, medium-bedded sandstone unit; 1,500 to 2,700 feet (457 to 823 m) thick.*

Irish Valley Member (Dci)—*Interbedded grayish-red and light-olive-gray sandstone, siltstone, and shale, overlain by upward-fining cycles of gray sandstone and grayish-red siltstone and silty claystone. Positions of conglomeratic sandstones (including the Kingsmill) are marked by open circles. Member is 2,500 to 3,150 feet (762 to 960 m) thick.*

Forms rolling hills of moderate relief; moderate to steep natural slopes; good surface drainage. Low to moderate resistance to weathering; weathered mantle moderate. Fractures well developed, with moderate to wide spacing. Excavation easy to moderately difficult, blasting may be required; cut-slope stability moderate to good; foundation stability moderate to very good. Good source for general fill. Ground-water quality good; fair to good yields from wells.

Dth

TRIMMERS ROCK AND HARRELL FORMATIONS, UNDIVIDED

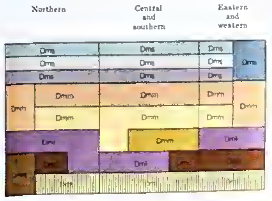
Trimmers Rock Formation—Light-olive-gray and medium-gray siltstone and silty shale, with interbedded very fine grained sandstone in upper part; graded bedding common in siltstone and sandstone beds, load casts prominent in upper part; 2,000 to 2,500 feet (610 to 762 m) thick.

Harrell Formation—Dark- to light-olive-gray and medium-light-gray silty shale which is noncalcareous, nonfossiliferous, and has a splintery fracture; 200 feet (61 m) thick.

Forms rolling hills of moderate relief; moderate to steep natural slopes; good surface drainage. Moderate resistance to weathering; weathered mantle thin to moderate. Fractures very well developed, very regular, with close spacing. Excavation moderately difficult, blasting may be required; cut-slope stability moderate to good; foundation stability good. Good source for crushed stone and general fill. Ground-water quality good, occasional H_2S odor, fair yields from wells.

DEVONIAN

Middle Devonian



MAHANTANGO FORMATION

Sherman Ridge Member (Dms)—*Light-olive-gray, fossiliferous, silty claystone with two interbedded siltstone to very fine grained sandstone units. These two submembers are cyclic units in which the grain size gradually increases towards the top. Sandstone at the top of the lower cycle is informally called the "Shadle sandstone." Member is 500 to 700 feet (152 to 213 m) thick.*

Montebello Member (Dmm)—*Light-olive-gray, medium-light-gray, and dusky-yellow, very fine to medium-grained, locally conglomeratic, siliceous, fossiliferous sandstone with interbedded gray siliceous siltstone and silty claystone, arranged in coarsening-upward cycles. Submember contacts shown on map are drawn on the tops of sandstone beds which are overlain by finer grained rocks at the base of the succeeding cycle; 200 to 900 feet (61 to 274 m) thick.*

Fisher Ridge Member (Dmf)—*Interbedded (generally laminated) olive-gray and medium-gray shale, siltstone, and very fine grained sandstone; 100 to 700 feet (30 to 213 m) thick.*

Dalmatia Member (Dmd)—*Light olive-gray, very fine to coarse-grained sandstone, 0 to 200 feet (61 m) thick.*

Turkey Ridge Member (Dmt)—*Light-gray to olive-gray, very fine to medium-grained, medium- and thick-bedded, planar-bedded subgraywacke sandstone; typically develops spheroidal or ellipsoidal exfoliation, locally very siliceous; locally includes Dalmatia Member (Dmd); 100 feet (30 m) thick.*

Forms ridges of moderately high relief and adjoining valleys of low to moderate relief; moderate to very steep natural slopes; good surface drainage. Low to high resistance to weathering; weathered mantle thin to thick. Fractures well developed, with moderate to wide spacing. Excavation easy to very difficult, blasting required; cut-slope stability moderate to very good; foundation stability good to excellent. Good source of crushed stone and building stone, possible source of clay-shale. Ground-water quality good, occasional H_2S odor, fair to good yields from wells.

Dmr

MARCELLUS FORMATION

Highly fissile, dark-gray to black, carbonaceous, noncalcareous shale; commonly has dark-yellowish-orange limonite staining on fracture surfaces. Light-gray, fine-grained orthoquartzite sandstone occurs in middle part of formation in the northeast; 106 feet (32 m) thick.

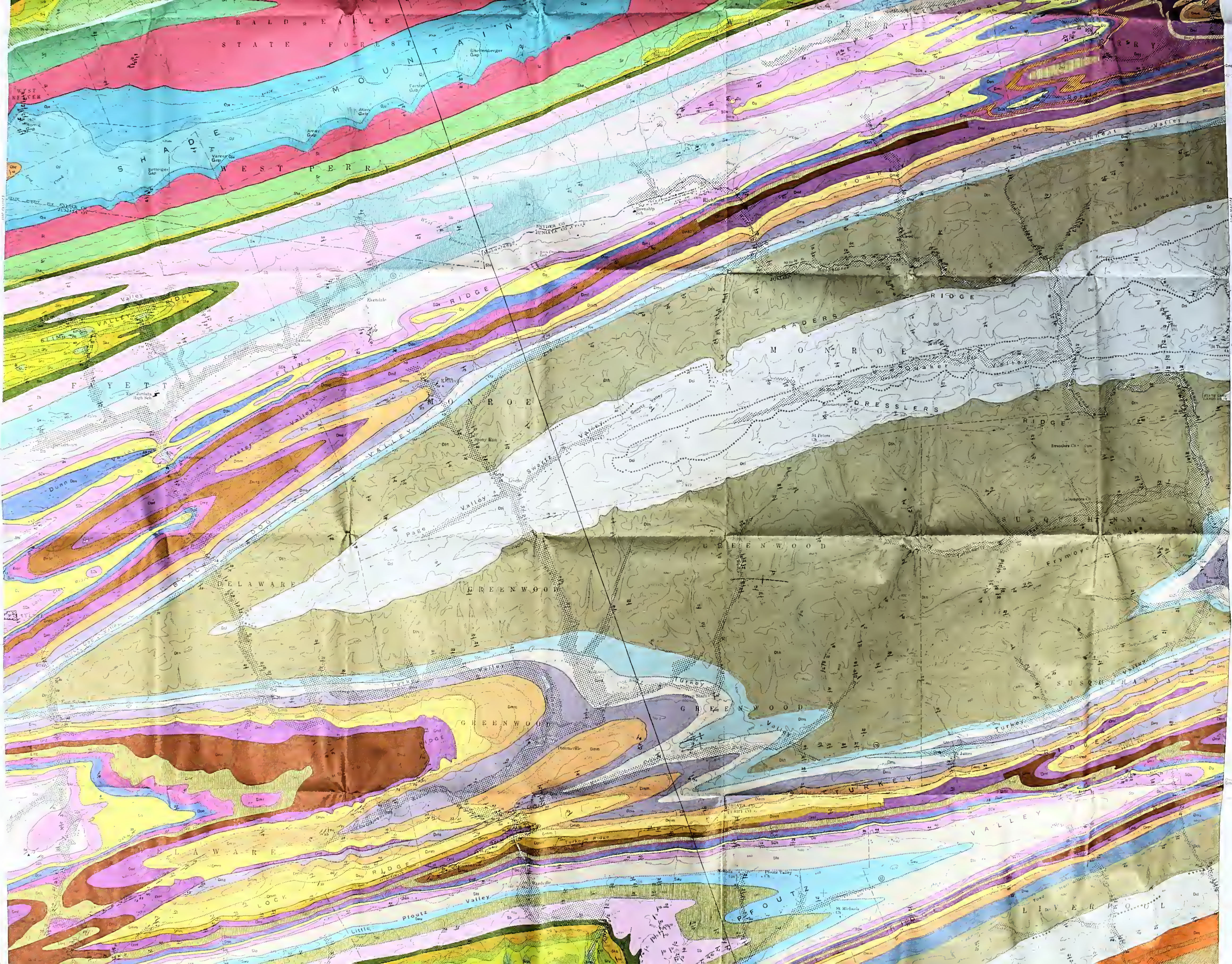
Forms valleys of moderate relief; moderate to fairly steep natural slopes; good surface drainage. Moderate resistance to weathering; weathered mantle moderate to thick. Fractures moderately well developed, with moderate spacing. Excavation easy; cut-slope stability low to moderate; foundation stability good. Good source for general fill. Ground-water quality good, occasional H_2S odor, good yields from wells.

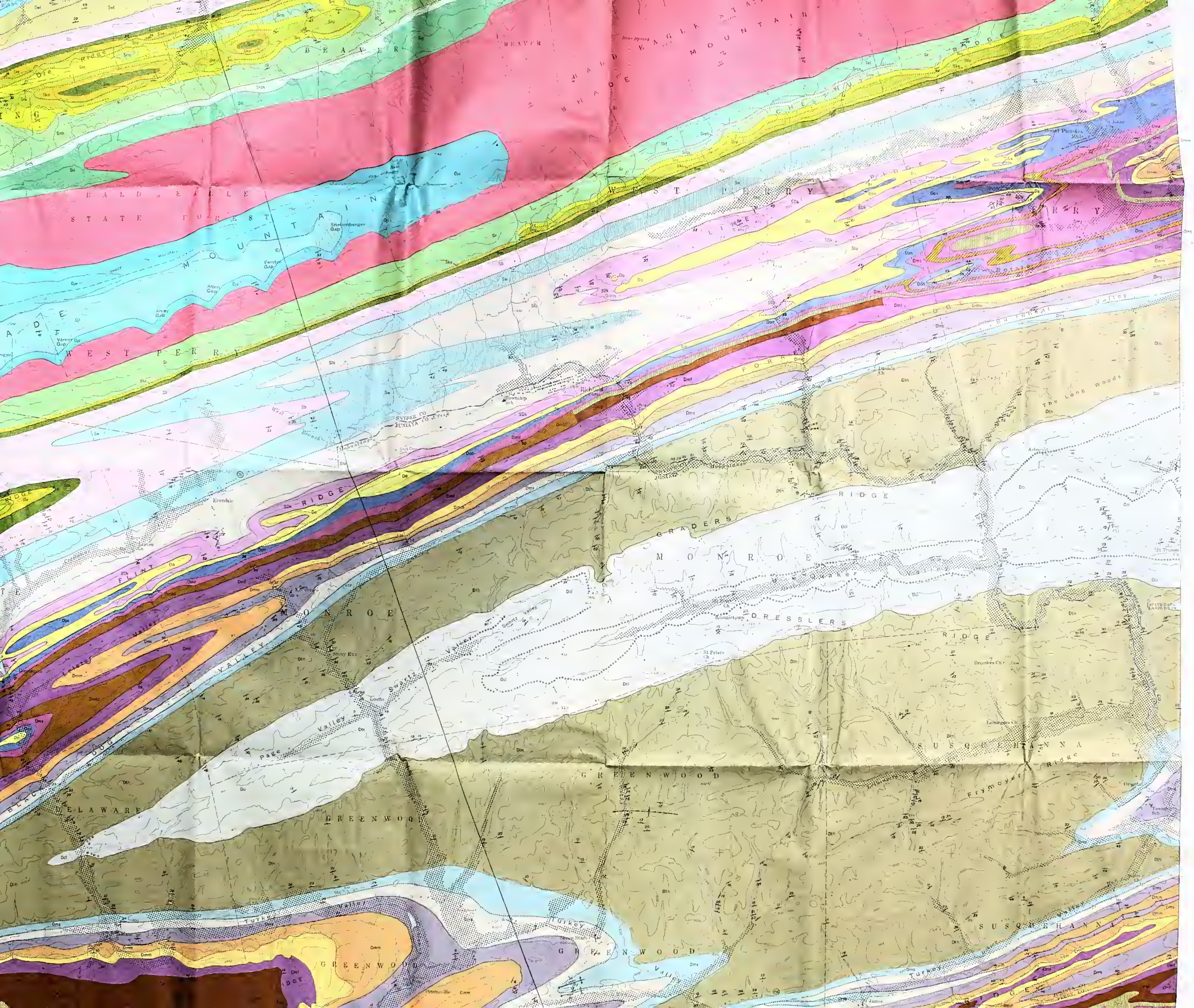
Don

ONONDAGA FORMATION

Gray limestone and shale, lower part

Forms narrow valleys of moderate


BALD EAGLE
STATE FOREST
MOUNTAIN
SHADE
WEST PERRY
WEST BEAVER
Shellenberger Gap
Ferster Gap
Aikey Gap
Arney Gap
Varner Gap
Betteiger Gap
SNYDER CO
JUNIATA CO
Richfield
Township Sch
RIDGE
FORD
Buckwheat Valley
The Long Woods
GRADERS
RIDGE
MONROE
Quaker Valley
DRESSLERS
RIDGE
St Peters
Dresslers Ch
Swartz Valley
Evendale
FLINT
FAYETTE
East Juniata High Sch
MONROE
VALLEY
DOG
BLACK
Page Valley
Stony Run
DELAWARE
GREENWOOD
SUSQUEHANNA
Frymoyer
Turkey Valley
GREENWOOD
Thomasville
Turkey Ridge
JUNIATA CO
PERRY CO
DELAWARE
LOCK
RIDGE
Little Ploutz Valley
PFOUTZ
Ploutz Valley
St Michaels
VALLEY
LIVERPOOL



MISSISSIPPIAN

Middle Mississippian

Lower Mississippian

Mmc

MAUCH CHUNK FORMATION

Grayish-red and gray argillaceous siltstone and silty shale; gray, medium- to coarse-grained, crossbedded conglomeratic sandstone and light-gray quartz-pebble conglomerate in lower part. 2,000+ feet (610+ m) thick.

Forms rolling valleys of low to moderate relief, moderate to fairly steep natural slopes, good surface drainage. Low to moderate resistance to weathering, weathered mantle moderate to thick. Fractures poorly developed, with wide spacing. Excavation easy to moderate, cut-slope stability poor to moderate, foundation stability fair to moderate. Good source for general fill. Ground water probably good quality, with low yields.

Mpm

Mpb

Dsk

POCONO FORMATION

Mount Carbon Member (Mpm)—Gray to buff, medium-grained, medium- to very thick bedded, crossbedded sandstone with beds and lenses of white quartz-pebble conglomerate in lower part, [illegible] feet ([illegible] m) thick.

Beckville Member (Mpb)—Gray to buff, medium-grained, medium- to very thick bedded, crossbedded sandstone with beds and lenses of white quartz-pebble conglomerate in lower part; includes a few rare thin coal seams, [illegible] feet (49 m) thick.

Spechty Kopf Member (Dsk)—Gray, fine- and medium-grained sandstone and dark-gray argillaceous siltstone; prominent conglomeratic beds near middle and base. 435 feet (133 m) thick.

Forms ridges and mountains of high relief, fairly to very steep natural slopes, good surface drainage. Very high resistance to weathering, weathered mantle thin to thick, bouldery. Fractures well developed, with wide spacing. Excavation difficult, blasting required, cut-slope stability very good, foundation stability excellent. Adequate source for building stone. Ground-water quality good, occasional high iron content, good yields from wells.

Upper Devonian

Dcd

Dcs

Dci

CATSKILL FORMATION

Duncannon Member (Dcd)—Asymmetric upward-fining cycles in which a basal gray, fine- to medium-grained, locally conglomeratic sandstone is overlain by very fine grained grayish-red sandstone, grayish-red siltstone, and red silty claystone; cycles have erosional basal surfaces. 1,900 to 3,000 feet (579 to 914 m) thick.

Sherman Creek Member (Dcs)—Dominantly grayish-red silty claystone, siltstone, and very fine grained crossbedded sandstone, with a prominent medium-gray, very fine to medium-grained, medium-bedded sandstone unit. 1,500 to 2,700 feet (457 to 823 m) thick.

Irish Valley Member (Dci)—Interbedded grayish-red and light-olive-gray sandstone, siltstone, and shale, overlain by upward-fining cycles of gray sandstone and grayish-red siltstone and silty claystone. Positions of conglomeratic sandstones (including the Kingsmill) are marked by open circles. Member is 2,500 to 3,150 feet (762 to 960 m) thick.

Forms rolling hills of moderate relief, moderate to steep natural slopes, good surface drainage. Low to moderate resistance to weathering; weathered mantle moderate. Fractures well developed, with moderate to wide spacing. Excavation easy to moderately difficult, blasting may be required, cut-slope stability moderate to good; foundation stability moderate to very good. Good source for general fill. Ground-water quality good, low to good yields from wells.

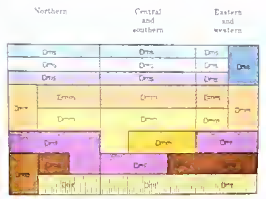
Dth

TRIMMERS ROCK AND HARRELL FORMATIONS, UNDIVIDED

Trimmers Rock Formation—Light-olive-gray and medium-gray siltstone and silty shale, with interbedded very fine grained sandstone in upper part; graded bedding common in siltstone and sandstone beds, load casts prominent in upper part. 2,000 to 2,500 feet (610 to 762 m) thick.

Harrell Formation—Dark- to light-olive-gray and medium-light-gray silty shale which is noncalcareous, nonfossiliferous, and has a splintery fracture. 200 feet (61 m) thick.

Forms rolling hills of moderate relief, moderate to steep natural slopes, good surface drainage. Moderate resistance to weathering, weathered mantle thin to moderate. Fractures very well developed, very regular, with close spacing. Excavation moderately difficult, blasting may be required, cut-slope stability moderate to good; foundation stability good. Good source for crushed stone and general fill. Ground-water quality good, occasional H_2S odor; fair yields from wells.



MAHANTANGO FORMATION

DEVONIAN

Middle Devonian

Sherman Ridge Member (Dms)—Light-olive-gray, fossiliferous, silty claystone with two interbedded siltstone to very fine grained sandstone units. These two submembers are cyclic units in which the grain size gradually increases towards the top. Sandstone at the top of the lower cycle is informally called the "Shells sandstone." Member is 500 to 700 feet (152 to 213 m) thick.

Montebello Member (Dmm)—Light-olive-gray, medium-light-gray, and dark-gray, very fine to medium-grained, locally conglomeratic, siliceous, fossiliferous sandstone with interbedded gray micaceous siltstone and silty claystone, grouped in coarsening-upward cycles. Submember contacts shown on map are drawn on the tops of sandstone beds which are overlain by finer grained rocks at the base of the succeeding cycle. 200 to 900 feet (61 to 274 m) thick.

Fisher Ridge Member (Dmf)—Interbedded, generally bioturbated, olive-gray and medium-gray shale, siltstone, and very fine grained sandstone. 100 to 700 feet (30 to 213 m) thick.

Dalmatia Member (Dmd)—Light-olive-gray, very fine to coarse-grained sandstone; 0 to 200 feet (60 m) thick.

Turkey Ridge Member (Dmt)—Light-gray to olive-gray, very fine to medium-grained, medium- and thick-bedded, planar-bedded subgraywacke sandstone, typically develops spheroidal or ellipsoidal exfoliation; locally very siliceous; locally includes Dalmatia Member (Dmd). 100 feet (30 m) thick.

Forms ridges of moderately high relief and adjoining valleys of low to moderate relief, moderate to very steep natural slopes; good surface drainage. Low to high resistance to weathering, weathered mantle thin to thick. Fractures well developed, with moderate to wide spacing. Excavation easy to very difficult, blasting required, cut-slope stability moderate to very good, foundation stability good to excellent. Good source of crushed stone and building stone, possible source of clay-shale. Ground-water quality good, occasional H_2S odor; fair to good yields from wells.

Dmr

MARCELLUS FORMATION

Highly fissile, dark-gray to black, carbonaceous, noncalcareous shale; commonly has dark-yellowish-orange limonite staining on fracture surfaces; light-gray, fine-grained subgraywacke sandstone occurs in middle part of formation in the northeast; 105 feet (32 m) thick.

Forms valleys of moderate relief, moderate to fairly steep natural slopes, good surface drainage. Moderate resistance to weathering, weathered mantle moderate to thick. Fractures moderately well developed, with moderate to wide spacing. Excavation easy, cut-slope stability low to moderate, foundation stability good. Good source for general fill. Ground-water quality good, occasional H_2S odor; good yields from wells.

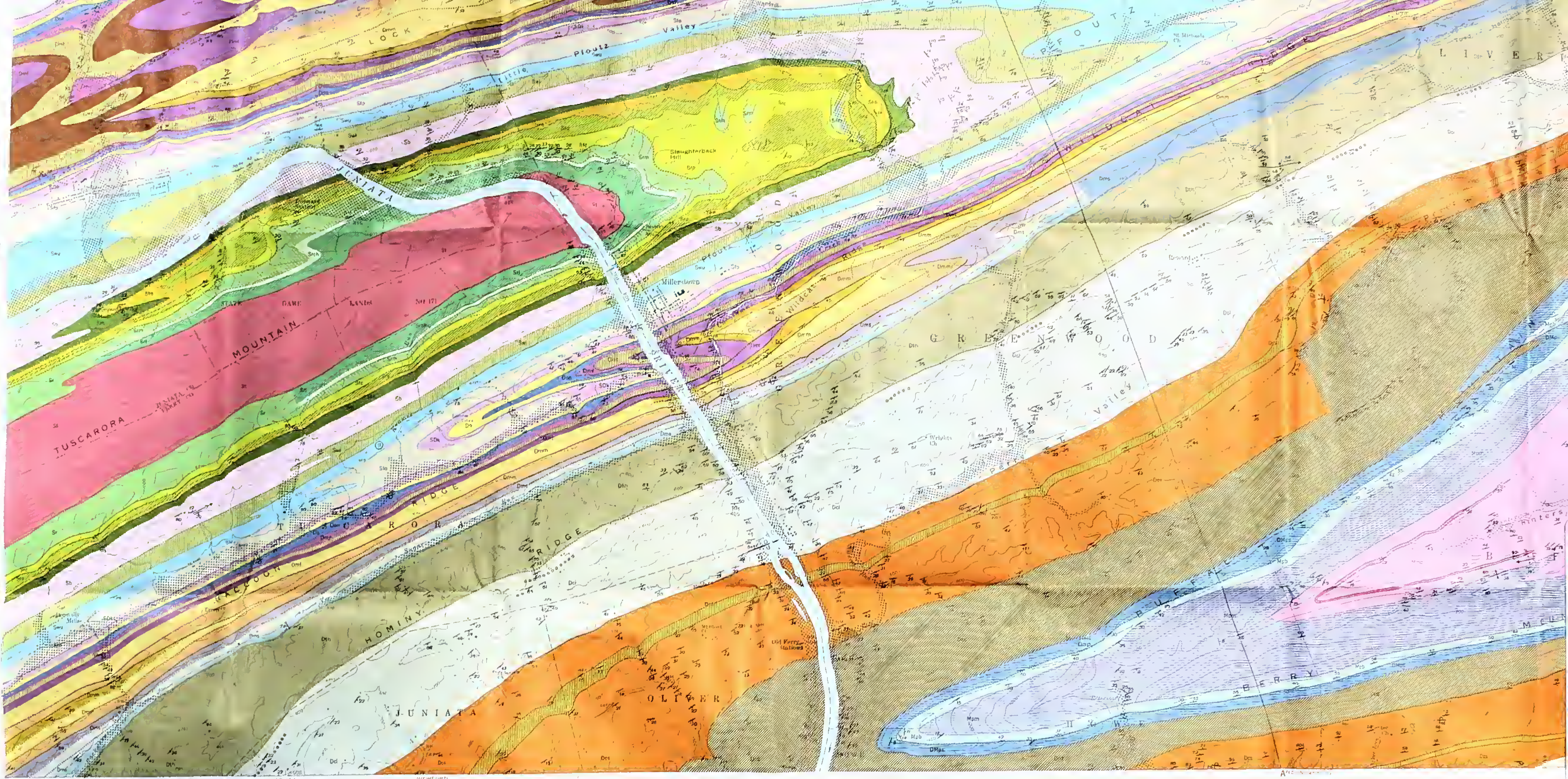
Doo

ONONDAGA FORMATION

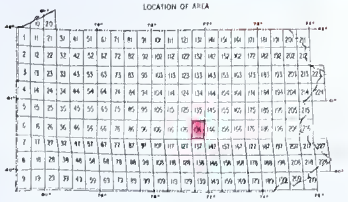
Gray limestone and shale; lower part (Needmore Member) is medium-gray, highly fissile shale which becomes slightly calcareous toward top, overlain by medium- to dark-gray, dense, fossiliferous, argillaceous, locally carbonaceous microcrystalline limestone (Selinsgrove Member). Tioga bentonite occurs at the top; 165 feet (50 m) thick.

Forms narrow valleys of moderate relief; gentle to moderate natural slopes, fair surface drainage. Low resistance to weathering, weathered mantle moderate to thick. Fractures well developed, with moderate spacing. Excavation easy to moderate; cut-slope stability fair, foundation stability good, possible [illegible] and [illegible] areas. Source for general fill. Ground-water quality good, occasional H_2S odor; fair yields from wells.

Do



Base map from U.S. Geological Survey Beaver Springs, Richfield, Millerstown, and Reward 7½-minute quadrangles.

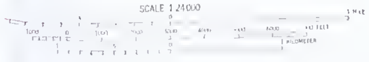


GEOLOGIC MAP OF THE MILLERSTOWN 15-MINUTE QUADRANGLE, PENNSYLVANIA

BY

RODGER T. FAILL AND RICHARD B. WELLS

1974



SCALE 1:24000

CONTOUR INTERVAL 20 FEET
DATUM IS MEAN SEA LEVEL

SYMBOLS

Contact
Dashed where approximately located; dotted where

Strike and dip of beds

Approximate strike and dip of beds

Strike and dip of overturned beds

Strike of vertical beds
Placement of 90 indicates tops of be

Horizontal beds

Fault
Dashed where approximately located; dotted were inferred

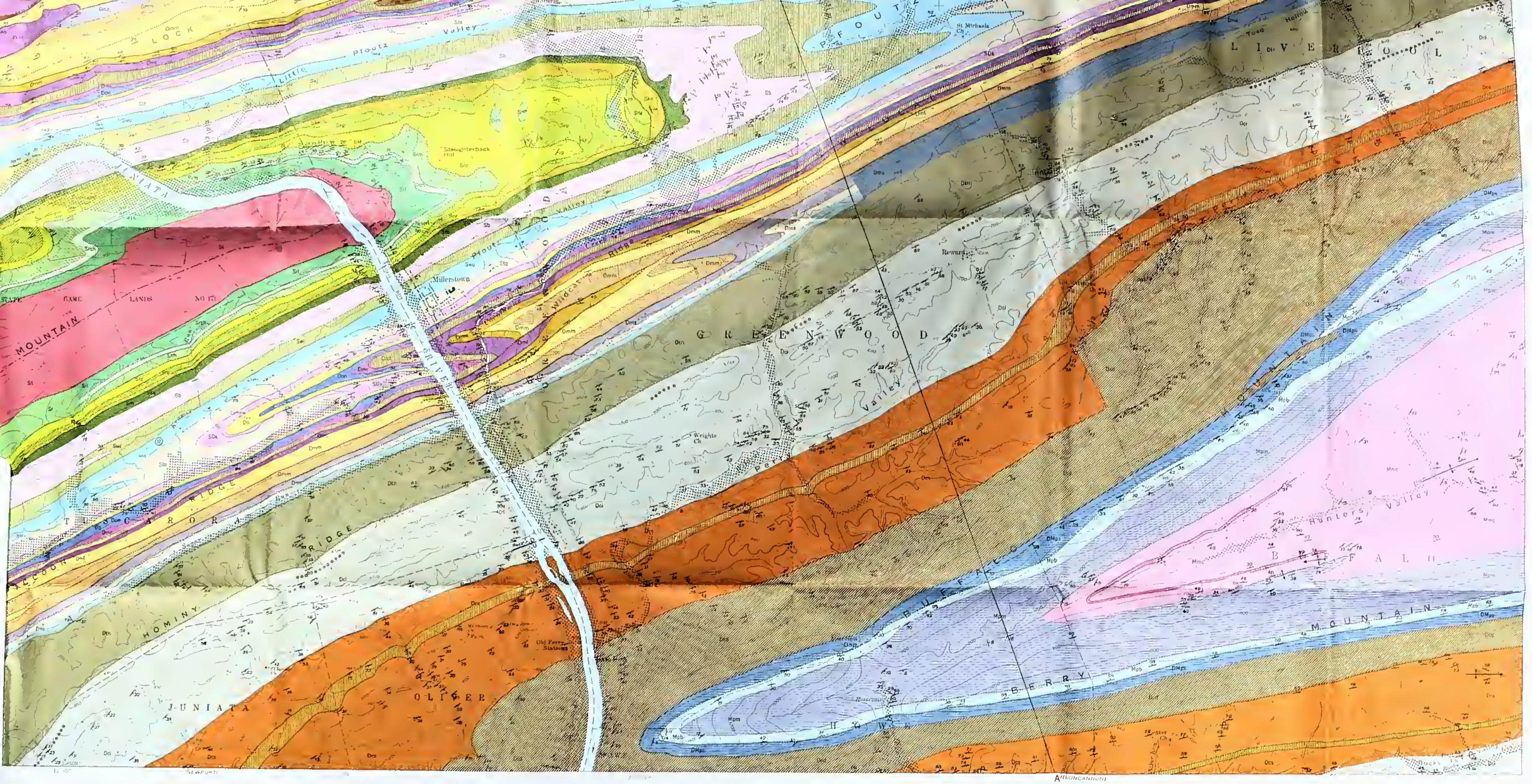
Strike and plunge direction of axis of major anticline

Strike and plunge direction of axis of major syncline

Strike and plunge of minor anticline

Strike and plunge of minor syncline

A——A'
Line of cross section



Geology based upon field mapping done from 1965-1970.
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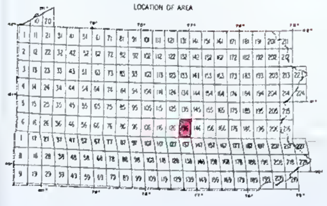
GEOLOGIC MAP OF THE MILLERSTOWN 15-MINUTE QUADRANGLE, PENNSYLVANIA

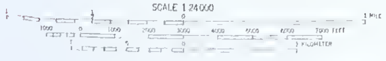
BY

RODGER T. FAILL AND RICHARD B. WELLS

1974

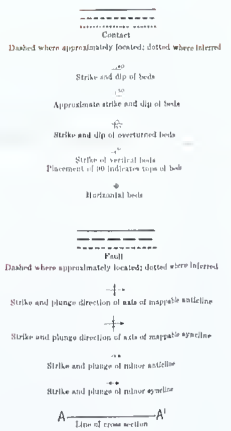
LOCATION OF AREA





CONTOUR INTERVAL 20 FEET
DATUM IS MEAN SEA LEVEL

SYMBOLS



Contact
Dashed where approximately located; dotted where inferred

Strike and dip of beds

Approximate strike and dip of beds

Strike and dip of overturned beds

Strike of vertical beds
Placement of 90 indicates tops of beds

Horizontal beds

Fault
Dashed where approximately located; dotted where inferred

Strike and plunge direction of axis of mappable anticline

Strike and plunge direction of axis of mappable syncline

Strike and plunge of minor anticline

Strike and plunge of minor syncline

A——A'
Line of cross section

▨

ALLUVIUM

Probably mud, silt, sand, or gravel. This information was derived solely from aerial photographs and has not been field checked.

SILURIAN

Upper Silurian

[illegible] Moderate resistance to weathering, weathered mantle thin to moderate. Fractures well developed, close to moderate spacing and widely spaced fracture cleavage. Excavation moderately difficult, blasting usually required; cut-slope stability fair to moderate; foundation stability fair to good, should be investigated for [illegible] areas. Good source for [illegible] agricultural lime, crushed stone, and building stone. [illegible] at depth. Ground water [illegible] good yields.

Tol

TONOLOWAY FORMATION

Medium-gray, laminated to thin-bedded limestone, with some beds of medium-gray calcareous shale, 500 to 600 feet (152 to 183 m) thick.

Forms rolling valleys [illegible] moderate [illegible] drainage. [illegible] low to moderate [illegible] weathered mantle [illegible] moderately well developed [illegible] spacing. Excavation [illegible] difficult, blasting [illegible] cut-slope stability [illegible] foundation stability [illegible] collapse [illegible] building stone [illegible] generally good, may [illegible] calcium sulfate [illegible] good yields from wells.

Swc | Swcu
 | Swcl

WILLS CREEK FORMATION

Predominantly [illegible] calcareous [illegible] light gray, fine-grained [illegible] stone, medium-gray [illegible] grayish-red silty claystone. [illegible] into two [illegible] members [illegible] upper member [illegible] lower member [illegible] total thickness [illegible] to 800 feet (152 to 244 m) [illegible]

Forms rolling [illegible] relief [illegible] slopes, good surface [illegible] weathered [illegible] to thick. Fractures [illegible] with [illegible] spacing [illegible] moderately difficult [illegible] fair to good, foundation [illegible] to good. Adequate [illegible] Ground-water quality [illegible] good, may contain [illegible] sulfate and iron, fair yields [illegible]

Sb

BLOOMSBURG FORMATION

Grayish-red claystone and shale, locally fossiliferous, grayish-red, very fine to fine-grained, silty, argillaceous, hematitic sandstone at base and near top, contains a few thin, light-gray, fine- to medium-grained sandstone beds in upper part, 150 to 180 feet (46 to 55 m) thick.

Forms rolling valleys and [illegible] low relief, moderate to [illegible] natural slopes, good surface [illegible] Low to moderate resistance to weathering, weathered mantle thin to moderate. Fractures poorly developed, [illegible] spacing, irregular cleavage [illegible] Excavation easy to moderately difficult, cut-slope stability fair to good, foundation stability good. Good source [illegible] ceramic clay and bricks and general fill; gas shows at depth. Ground water quality good, good yields from wells.

Sm

MIFFLINTOWN FORMATION

Dark-gray, silty, calcareous shale and medium- to dark-gray, bioclastic and micritic to microcrystalline, medium- to thin-bedded, planar-bedded limestone, 150 feet (46 m) thick.

Forms rolling valleys of moderate [illegible] gentle to moderate natural [illegible] fair surface drainage. Low to moderate resistance to weathering, weathered mantle moderate to thick [illegible] features may be present. Fractures moderately well developed, with [illegible] moderate spacing. Excavation [illegible] moderately difficult, cut-slope stability fair to good, foundation stability good, possible local collapse areas [illegible] for general fill. Ground-water quality good, poor yields from wells.

Middle Silurian

Sk

KEEFER FORMATION

Light- to dark-gray, very fine to coarse-grained, fossiliferous, siliceous, very thin to thick-bedded, crossbedded sandstone, locally hematitic, locally conglomeratic, 35 feet (12 m) thick.

Forms hills of low to moderate relief, moderate to steep natural slopes, good surface drainage. High resistance to weathering, weathered mantle thin and often bouldery. Fractures well developed, with moderate to wide spacing. Excavation difficult, blasting required, cut-slope stability very good, foundation stability excellent. Former source of iron ore and building stone. Ground water probably good quality with poor yields.

Sr | Sru
 | Src
 | Srm
 | Srl
 | Srl

ROSE HILL FORMATION

Upper shaly member ([illegible]): Medium-dark-gray shale, locally micaceous and calcareous, and interbedded medium-light- to medium-dark-gray bioclastic calcarenitic limestone, thin-bedded, planar-bedded, and locally pyritic, 114 feet (35 m) thick.

Center Member (Src): Dark reddish-gray to blackish-red hematitic sandstone and sandy siltstone, with interbedded gray to red shales, 79 feet (24 m) thick.

Middle shaly member (Srm): Medium-light-gray and light-olive-gray shale and siltstone; locally becomes slightly calcareous and fossiliferous, 360 feet (110 m) thick.

Cabin Hill Member (Srm): Dark-reddish-gray to blackish-red hematitic sandstone and sandy siltstone, with interbedded gray to red shales, 12½ feet (4 m) thick.

Lower shaly member ([illegible]): Medium-light-gray and light-olive-gray shale, generally finely silty, sub-fissile, and fairly to poorly fissile, interbedded with light-olive-gray to medium-light-gray siltstone, slightly argillaceous and siltstone thin- to very thin-bedded, and ripple marked, 370 feet (116 m) thick.

Forms hills of moderate relief, and lower slopes of mountains, moderate to fairly steep natural slopes, good surface drainage. Moderate to high resistance to weathering, weathered mantle thin to moderate. Fractures moderately to well developed, with close to moderate spacing. Excavation moderate to difficult, some blasting required, cut-slope stability moderate to good, foundation stability good. Potential source of clay-shale and iron ore, good source for general fill. Ground-water quality good, good yield from wells.

Lower Silurian

St

TUSCARORA FORMATION

Light-gray to white, fine- to medium-grained, medium-bedded, siliceous sandstone, interbedded in upper part with medium-gray and olive-gray silty shale, 600 feet (183 m) thick.

Forms ridges and mountains of high relief, fairly to very steep natural slopes, good surface drainage. Very high resistance to weathering, weathered mantle thin to moderate, bouldery talus slopes on mountain sides. Fractures well developed, with moderate to wide spacing. Excavation very difficult, blasting required; cut-slope stability very good; foundation stability excellent. Good source for silica bricks, building stone, railroad ballast, and embankment facing. Ground water probably good quality with poor yields.

ORDOVICIAN

Upper Ordovician

Oju
Ojl

JUNIATA FORMATION

Upper part (Oju) is grayish-red, very fine to medium-grained, crossbedded graywacke sandstone; lower part (Ojl) is grayish-red siltstone and silty claystone, total thickness 730 feet (222 m).

Forms ridges of high relief and valleys of moderate relief, fairly to very steep natural slopes, good surface drainage. Moderate to high resistance to weathering, weathered mantle thin to moderate. Fractures well developed, with moderate to wide spacing. Excavation moderate to difficult, blasting required, cut-slope stability good to very good, foundation stability good to excellent. Adequate for general fill, oil shows at depth. Ground water probably good quality with fair yields.

Obe

BALD EAGLE FORMATION

Gray, medium- to thick-bedded, crossbedded, medium- to coarse-grained sandstone and quartz-pebble conglomerate; 730+ feet (222+ m) thick.

Forms mountain ridges and rolling, steep terrain, fairly to very steep natural slopes, good surface drainage. High resistance to weathering, weathered mantle thin to moderate, bouldery. Fractures well developed, with moderate spacing. Excavation difficult, blasting required, cut-slope stability very good, foundation stability excellent. Source for riprap and embankment facing. Ground water probably good quality with fair yields.

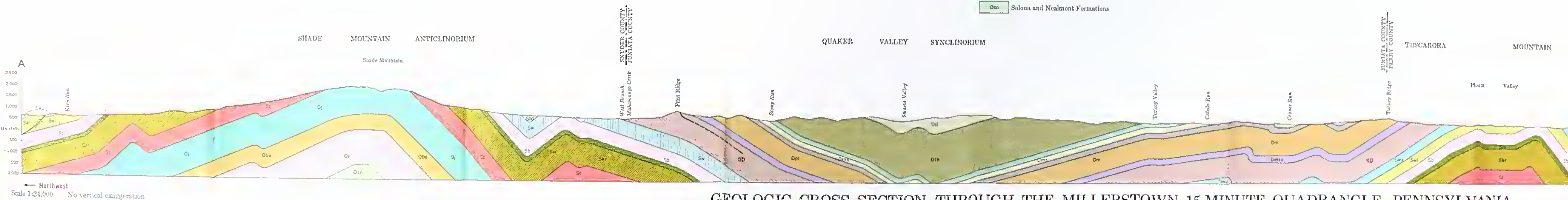
TOPOGRAPHIC AND GEOLOGIC SURVEY
Arthur A. Socolow, *State Geologist*

COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF ENVIRONMENTAL RESOURCES

EXPLANATION

Section trends N20W and passes through the center of the quadrangle. See line A-A′ on Plates 1 and 5. Stratigraphic abbreviations are the same as those used on the geologic map (Plate 1) except for the following units:

Dm	Montebello, Fisher Ridge, Dalmatia, and Turkey Ridge Members, Mahantango Formation
Dmo	Marcellus and Onondaga Formations
SD	Old Port, Keyser, and Tonoloway Formations
Skr	Keefer and Rose Hill Formations
Oj	Juniata Formation
Or	Reedsville Formation
Osn	Salona and Nealmont Formations



GEOLOGIC CROSS SECTION THROUGH THE MILLERSTOWN 15-MINUTE QUADRANGLE, PENNSYLVANIA

COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF ENVIRONMENTAL RESOURCES

EXPLANATION

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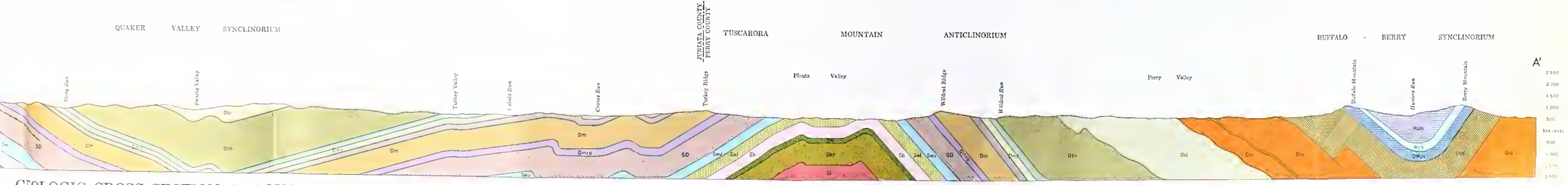
Oj	Juniata Formation
Or	Reedsville Formation
Osn	Salona and Nealmont Formations

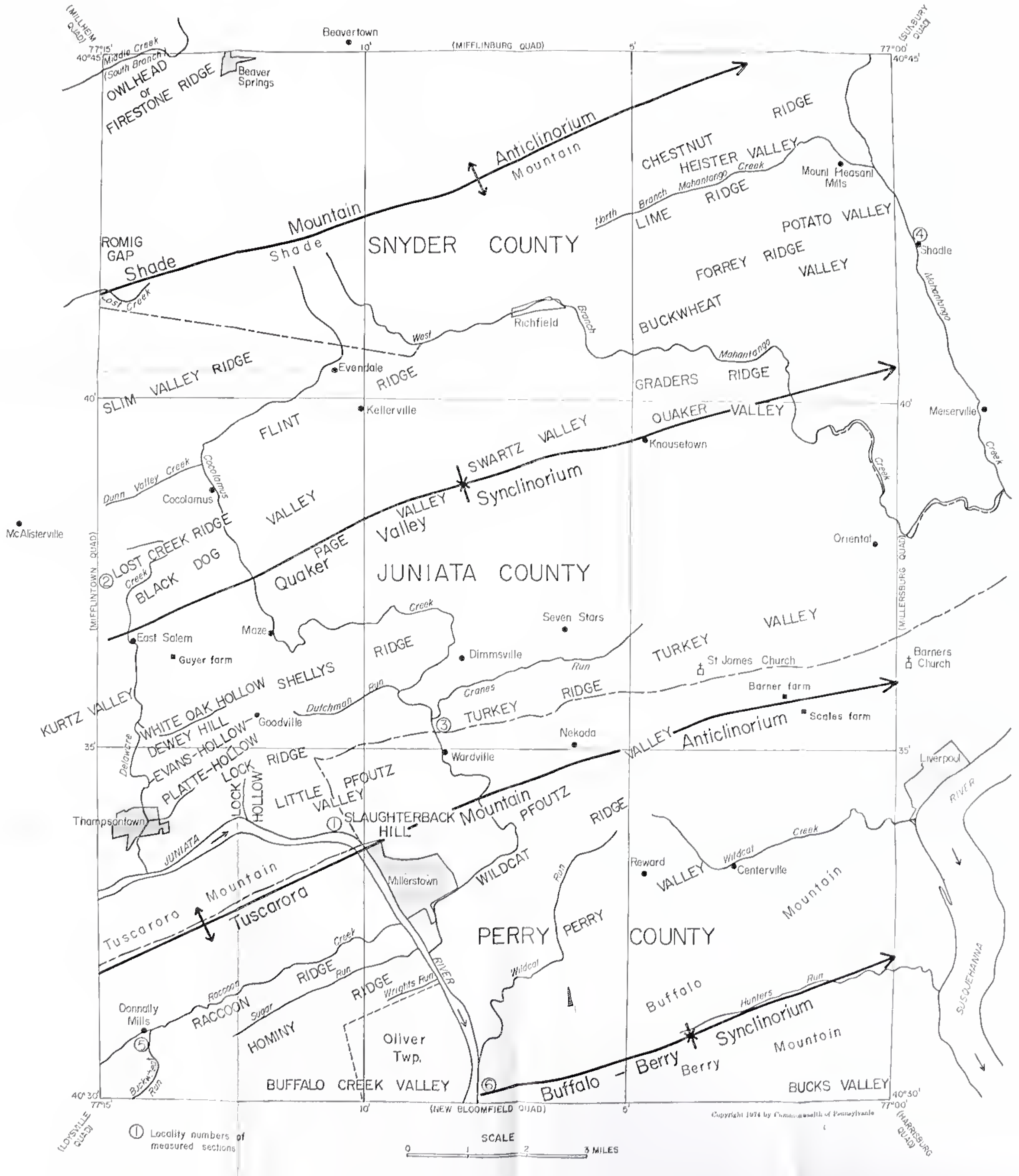


GEOLOGIC CROSS SECTION THROUGH THE MILLERSTOWN 15-MINUTE QUADRANGLE, PENNSYLVANIA

TOPOGRAPHIC AND GEOLOGIC SURVEY
Arthur A. Socolow, *State Geologist*

COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF ENVIRONMENTAL RESOURCES

Atlas 136, Plate 3



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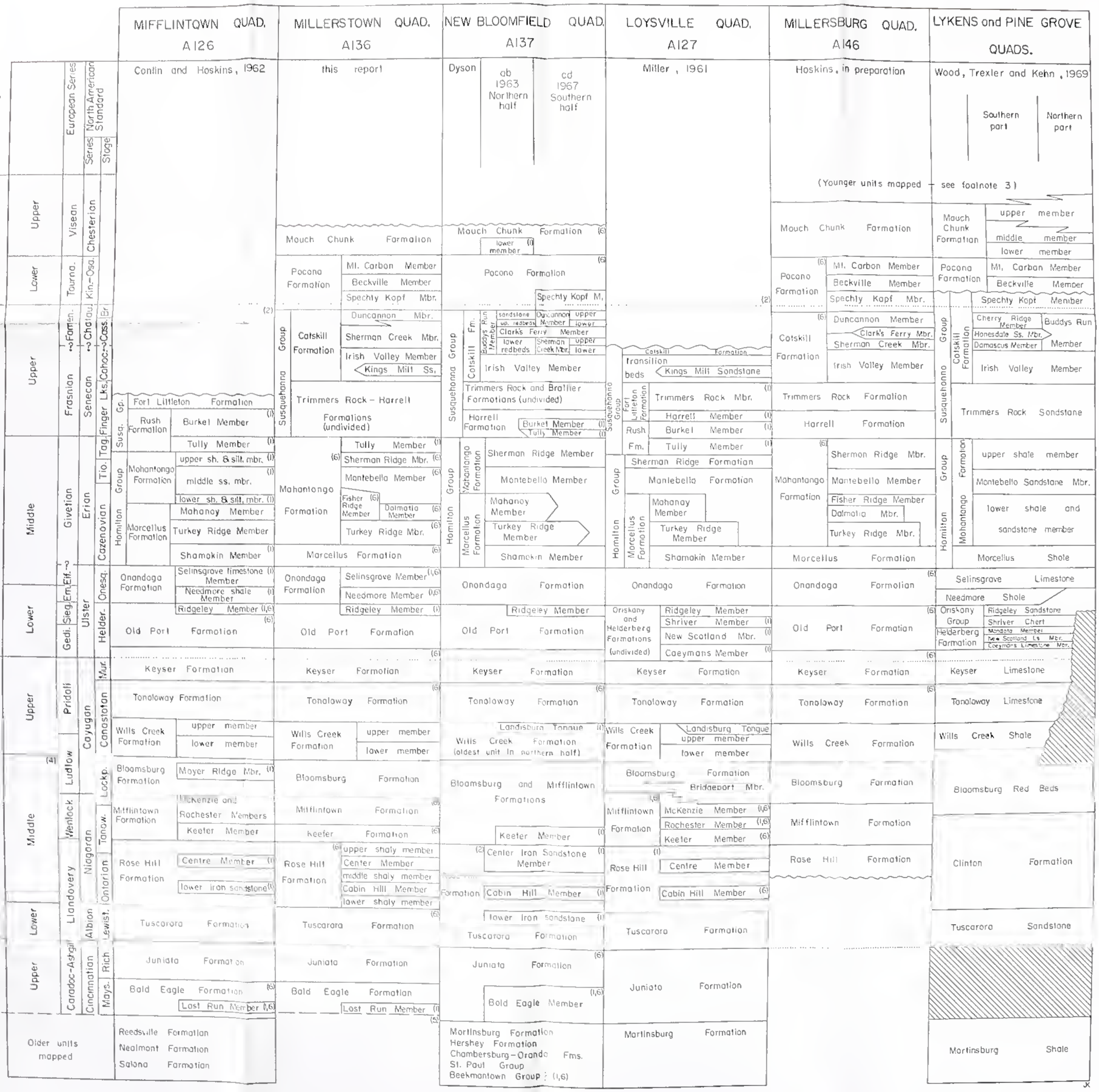
TOPONYMIC MAP OF THE MILLERSTOWN 15-MINUTE QUADRANGLE, PENNSYLVANIA
SHOWING LOCATION OF TOWNS, VILLAGES, MAJOR STREAMS, AND OTHER PHYSICAL FEATURES REFERRED TO IN TEXT

TOPOGRAPHIC AND GEOLOGIC SURVEY
Arthur A. Socolow, *State Geologist*

COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF ENVIRONMENTAL RESOURCES

Atlas 136, Plate 4

STRATIGRAPHIC CORRELATION CHART FOR THE MILLERSTOWN 15-MINUTE QUADRANGLE AND ADJACENT AREAS



System	Series	European Series	North American Standard Series	Stage	MIFFLINTOWN QUAD. A126	MILLERSTOWN QUAD. A136	NEW BLOOMFIELD QUAD. A137	LOYSVILLE QUAD. A127	MILLERSBURG QUAD. A146	LYKENS and PINE GROVE QUADS.
					Conlin and Hoskins, 1962	this report	Dyson ab 1963 Northern half; cd 1967 Southern half	Miller, 1961	Hoskins, in preparation	Wood, Trexler and Kehn, 1969 Southern part; Northern part
									(Younger units mapped — see footnote 3)	
MISSISSIPPIAN	Upper	Visean	Chesterian			Mauch Chunk Formation	Mauch Chunk Formation (6) lower member (1)		Mauch Chunk Formation	Mauch Chunk Formation: upper member middle member lower member
	Lower	Tourna.	Kin.-Osa.			Pocono Formation: Mt. Carbon Member Beckville Member Spechty Kopf Mbr.	Pocono Formation (6) Spechty Kopf M.		Pocono Formation (6): Mt. Carbon Member Beckville Member Spechty Kopf Mbr. (2)	Pocono Formation: Mt. Carbon Member Beckville Member Spechty Kopf Member
DEVONIAN	Upper	Famen.	Chatau.	Cass.	(2)	Susquehanna Group, Catskill Formation: Duncannon Mbr. Sherman Creek Mbr.	Susquehanna Group, Catskill Fm.: Buddys Run Member (sandstone, up. redbeds) Duncannon Member (upper, lower) Clarks Ferry Member lower redbeds Sherman Creek Mbr. (upper, lower)	Catskill Formation	Catskill Formation (6): Duncannon Member Clark's Ferry Mbr. Sherman Creek Mbr.	Susquehanna Group, Catskill Formation: Cherry Ridge Member Honesdale Ss. Mbr. Damascus Member Buddys Run Member
		Frasnian	Senecan	Cohoc.		Irish Valley Member Kings Mill Ss.	Irish Valley Member	Transition beds Kings Mill Sandstone	Irish Valley Member	Irish Valley Member
				Finger Lks.	Susq. Gp.: Fort Littleton Formation Rush Formation: Burket Member (1)	Trimmers Rock – Harrell Formations (undivided)	Trimmers Rock and Brallier Formations (undivided) Harrell Formation: Burket Member (1) Tully Member (1)	Susquehanna Group, Fort Littleton Formation: Trimmers Rock Mbr. (1) Harrell Member (1) Rush Fm.: Burket Member (1)	Trimmers Rock Formation Harrell Formation	Susquehanna Group: Trimmers Rock Sandstone
	Middle	Givetian	Erian	Tag.	Tully Member (1)	Tully Member (1)		Tully Member (1)		
				Tio.	Hamilton Group, Mahantongo Formation: upper sh. & silt. mbr. (1) middle ss. mbr. (1) lower sh. & silt. mbr. (1)	Mahantongo Formation: (6) Sherman Ridge Mbr. (6) Montebello Member (6) Fisher Ridge Member (6) Dalmatia Member (6)	Hamilton Group, Mahantongo Formation: Sherman Ridge Member Montebello Member	Hamilton Group: Sherman Ridge Formation Montebello Formation	Mahantongo Formation (6): Sherman Ridge Mbr. Montebello Member Fisher Ridge Member Dalmatia Mbr.	Hamilton Group, Mahantongo Formation: upper shale member Montebello Sandstone Mbr. lower shale and sandstone member
				Cazenovian	Marcellus Formation: Mahanoy Member Turkey Ridge Member Shamokin Member (1)	Turkey Ridge Mbr. (6) Marcellus Formation (6)	Marcellus Formation: Mahanoy Member Turkey Ridge Member Shamokin Member	Marcellus Formation: Mahanoy Member Turkey Ridge Member Shamokin Member	Turkey Ridge Mbr. Marcellus Formation	Marcellus Shale
	Lower	Em.-Eif.?	Ulster	Onesq.	Onondaga Formation: Selinsgrove limestone Member (1) Needmore shale Member (1)	Onondaga Formation: Selinsgrove Member (1,6) Needmore Member (1,6)	Onondaga Formation	Onondaga Formation	Onondaga Formation (6)	Selinsgrove Limestone Needmore Shale
		Sieg. Gedi.		Helder.	Ridgeley Member (1,6) Old Port Formation (6)	Ridgeley Member (1) Old Port Formation	Ridgeley Member Old Port Formation (6)	Oriskany and Helderberg Formations (undivided): Ridgeley Member Shriver Member (1) New Scotland Mbr. (1) Caeymans Member (1)	Old Port Formation (6)	(6) Oriskany Group: Ridgeley Sandstone Shriver Chert Helderberg Formation: Mandata Member New Scotland Ls. Mbr. Coeymans Limestone Mbr.
SILURIAN	Upper	Pridoli	Cayugan	Mur.	Keyser Formation	Keyser Formation (6)	Keyser Formation (6)	Keyser Formation	Keyser Formation (6)	Keyser Limestone
				Canastotan	Tonoloway Formation	Tonoloway Formation (6)	Tonoloway Formation (6)	Tonoloway Formation	Tonoloway Formation (6)	Tonoloway Limestone
					Wills Creek Formation: upper member lower member	Wills Creek Formation: upper member lower member	Landisburg Tongue (1) Wills Creek Formation (oldest unit in northern half)	Wills Creek Formation: Landisburg Tongue upper member lower member	Wills Creek Formation	Wills Creek Shale
	(4)	Ludlow		Lockp.	Bloomsburg Formation: Moyer Ridge Mbr. (1)	Bloomsburg Formation	Bloomsburg and Mifflintown Formations	Bloomsburg Formation Bridgeport Mbr. (1,6)	Bloomsburg Formation	Bloomsburg Red Beds
	Middle	Wenlock	Niagaran	Tonaw.	Mifflintown Formation: McKenzie and Rochester Members Keefer Member	Mifflintown Formation (6) Keefer Formation (6)	Keefer Member (1)	Mifflintown Formation: McKenzie Member (1,6) Rochester Member (1,6) Keefer Member (6)	Mifflintown Formation	
		Llandovery		Ontarian	Rose Hill Formation: Centre Member (1) lower iron sandstone (1)	Rose Hill Formation: (6) upper shaly member Center Member middle shaly member Cabin Hill Member lower shaly member	Rose Hill Formation: (2) Center Iron Sandstone Member (1) Cabin Hill Member (1) lower iron sandstone (1)	Rose Hill Formation: (1) Centre Member Cabin Hill Member (6)	Rose Hill Formation	Clinton Formation
	Lower		Albion	Lewist.	Tuscarora Formation	Tuscarora Formation (6)	Tuscarora Formation	Tuscarora Formation		Tuscarora Sandstone
ORDOVICIAN	Upper	Caradoc-Ashgill	Cincinnatian	Rich.	Juniata Formation	Juniata Formation	Juniata Formation (6)	Juniata Formation		
				Mays.	Bald Eagle Formation (6) Lost Run Member (1,6)	Bald Eagle Formation Lost Run Member (1)	Bald Eagle Member (1,6)			
Older units mapped					Reedsville Formation Nealmont Formation Salona Formation	(5)	Martinsburg Formation Hershey Formation Chambersburg–Orando Fms. St. Paul Group Beekmantown Group (1,6)	Martinsburg Formation		Martinsburg Shale

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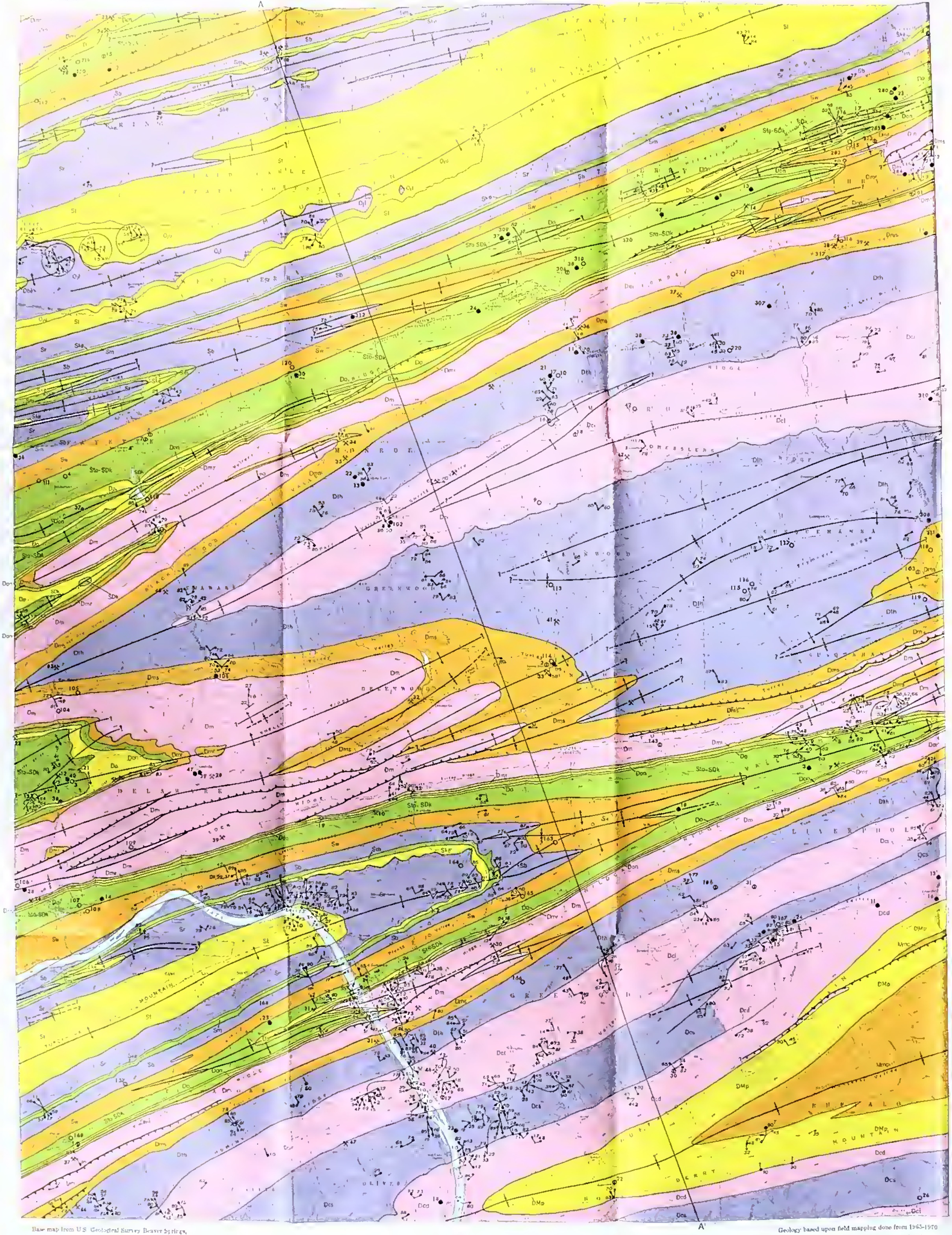
(1) Units discussed in text but not shown on geologic map.
(2) Dotted lines indicate time horizons.
(3) Younger units mapped:
Millersburg quadrangle: Pottsville Formation (Tumbling Run Member).
Lykens and Pine Grove quadrangles:
Pottsville Formation (Sharp Mountain, Schuylkill, and Tumbling Run Members)
Llewellyn Formation
(4) Silurian subdivisions:

Mifflintown quadrangle:
Lower: Tuscarora through Keefer
Middle: McKenzie-Rochester Member into Bloomsburg Formation
Upper: Bloomsburg into Keyser
Millerstown quadrangle:
Lower: Tuscarora Formation
Middle: Rose Hill through Bloomsburg Formations
Upper: Wills Creek into Keyser Formation

New Bloomfield quadrangle:
Lower: Tuscarora into Bloomsburg-Mifflintown Formations
Middle: Bloomsburg-Mifflintown into Wills Creek Formation
Upper: Wills Creek into Keyser Formation
Loysville quadrangle:
Lower: Tuscarora through Rochester Member
Middle: McKenzie Member through Bloomsburg
Upper: Wills Creek through Keyser Formation

Millersburg quadrangle: (not yet published)
Lykens and Pine Grove quadrangles:
Lower: Tuscarora Formation
Middle: Clinton Formation
Upper: Bloomsburg into Keyser
(5) See Penetration Chart, Figure 99, for subsurface units
(6) Measured section



Base map from U.S. Geological Survey Beaver Springs, Richfield, Millerstown, and Reward 7½-minute quadrangles.

Geology based upon field mapping done from 1965-1970
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TECTONIC AND ENVIRONMENTAL GEOLOGIC MAP OF THE MILLERSTOWN 15-MINUTE QUADRANGLE, PENNSYLVANIA

EXPLANATION

UNITS 1

Predominantly quartzitic sandstones or chert. Forms ridges of medium to high relief, with fairly to very steep natural slopes; good surface drainage. High resistance to weathering, weathered mantle thin to moderate, often bouldery, sometimes forms talus on mountain slopes. Fractures well developed, with moderate to wide spacing. Excavation difficult to very difficult, blasting required; cut-slope stability very good to excellent; foundation stability excellent.

UNITS 2

Predominantly sandstones, alternating with siltstones and minor shales. Forms ridges of medium relief, with fairly to very steep natural slopes; good surface drainage. Moderate to high resistance to weathering, weathered mantle thin to moderate. Fractures usually well developed, with close to wide spacing. Excavation moderate to very difficult, blasting usually required, cut-slope stability good to excellent; foundation stability good to excellent.

UNITS 3

Predominantly interbedded shales, siltstones, and sandstones. Forms ridges of moderate relief and rolling hills of moderate relief; moderate to steep natural slopes; good surface drainage. Low to moderate resistance to weathering; weathered mantle thin to thick. Fractures moderately to well developed, with close to moderate spacing. Excavation moderately difficult to moderately easy, blasting occasionally required; cut-slope stability fair to good; foundation stability good.

UNITS 4

Predominantly shale or calcareous shale, minor amounts of siltstone. Forms valleys of low to moderate relief, with gentle to moderate natural slopes; good to fair surface drainage. Low resistance to weathering; weathered mantle moderate to thick. Fractures poorly to moderately developed, with close to wide spacing. Excavation usually easy; cut-slope stability poor to fair; foundation stability fair to good.

UNITS 5

Predominantly limestone, minor amounts of shale. Forms valleys of low to moderate relief, with gentle to moderate natural slopes; poor to fair surface drainage, good to fair subsurface drainage. Low resistance to weathering; weathered mantle thin to thick; solution features may be present. Fractures moderately well developed, with close to moderate spacing. Excavation moderately difficult, blasting usually required; cut-slope stability fair to good; foundation stability poor to good, with possible collapse areas.

All rock-unit symbols are the same as those used on Plate 1, except for DMp (Pocono Formation) and Dm (Montebello, Fisher Ridge, Dalmatia, and Turkey Ridge members of Mahantango Formation, undivided)

SYMBOLS

Axial trace, anticlinal

Axial trace, synclinal

Thrust fault (sawteeth on upper plate)

Strike and dip of fracture sets

Direction and plunge of slickensides on bedding

Direction and plunge of slickensides on fractures

Mine or quarry, numbered and listed in Table 32

Water well; location known within 100 feet

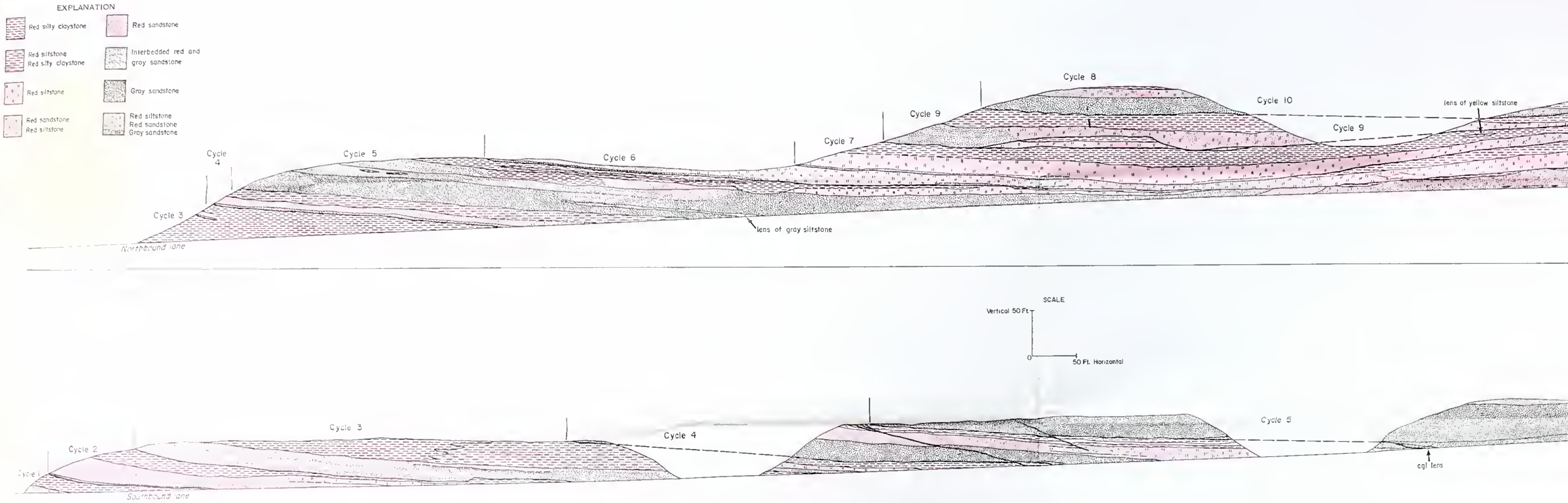
Water well; location known within 1,000 feet

Water well; location known within one mile

Wells are numbered and listed in Appendix IV-A.

TOPOGRAPHIC AND GEOLOGIC SURVEY
Arthur A. Socolow, State Geologist

COMMONWEALTH OF PENNSYLVANIA
DEPARTMENT OF ENVIRONMENTAL RESOURCES

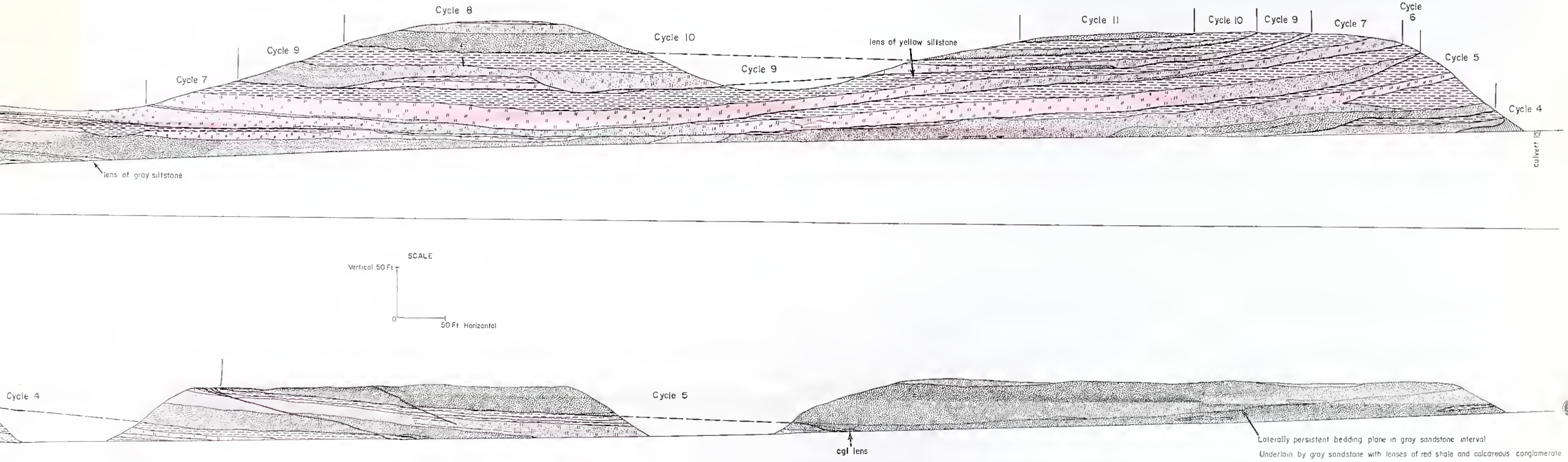


BUFFALO MOUNTAIN CROSS SECTION

Duncannon Member of Upper Devonian Catskill Formation exposed along U.S. Route 22–322 on the west end of Buffalo Mountain, Howe Township, Perry County. This outcrop is in the southeast corner of the Millerstown 7½-minute quadrangle, approximately 3.6 to 4.0 miles south of Millerstown. The upper section is the exposure along the northbound lane, and the lower sections are exposures along the southbound lane. The exposure lies on the axis of the Buffalo-Berry syncline, which is the westward extension of the northern trough of the Southern Anthracite Basin.

The Duncannon Member is highly cyclic, consisting of a repetition of fining-upward cycles. A typical cycle, illustrated in Figure 41, begins with gray, fine-grained sandstone overlying an erosion surface, overlain by reddish-gray, very fine grained sandstone, grayish-red siltstone, and red silty claystone. Locally, conglomerate lenses occur at the base of cycles, which consist of subangular clay chips, nodular or concretionary carbonate fragments, small (generally less than 1 cm in diameter) quartz pebbles, and wood fragments.

Parts of 11 major cycles are exposed here, ranging in thickness from 0 to 70 feet. Many of the cycles contain nested subcycles, which represent local interruptions of the general fining-upward pattern.



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